

**EFFECT OF SUSTAINED USAGE OF ENERGY EFFICIENT FIREWOOD COOK
STOVES ON CLIMATE CHANGE MITIGATION IN SIAYA COUNTY, KENYA**

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**A Thesis Submitted in Partial Fulfillment of the Requirements for the Award of the
Degree in Master of Science in Climate Change Adaptation and Sustainable
Development of Masinde Muliro University of Science and Technology.**

March, 2025

DECLARATION

This is to declare that this is my original work that has never been presented in any institution of higher learning for examination.

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DEDICATION

This work is especially dedicated to my family for the love, care, support and encouragement they accorded me.

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ABSTRACT

The significance of using energy efficient firewood cook stoves for climate change mitigation has gained wide acknowledgement leading to dissemination of different types of energy efficient firewood stoves in many rural households in Kenya. However, the anticipated benefits can be fully actualized only with the sustained usage of these stoves. Effect of sustained usage of the energy efficient firewood stoves on climate change mitigation in Siaya County, Kenya, remained lowly researched and unclear. The adopted stoves' usage rates, factors that influence their sustained usage and the relationship between the sustained usage and climate change mitigation had not been clearly established in Siaya. This study, therefore, evaluated the effect of sustained usage of energy efficient firewood cook stoves on climate change mitigation in Siaya. The specific objectives were to: (i) determine the usage rate of the energy efficient firewood cook stove in relation to the other stoves used by the households (ii) evaluate the sociocultural, economic and technological factors that influence sustained usage of the energy efficient firewood cook stoves; and (iii) determine the relationship between sustained usage of the energy efficient firewood stoves by households and climate change mitigation in Siaya County. The study employed mixed methods including descriptive survey and experimentation. The study participants were drawn from 127,242 households where twin brick rocket (an energy efficient firewood cook stove) had been installed, with 399 households participating in a survey and 100 participating in a Kitchen Performance Test (KPT). The KPT protocol adopted a paired-sample study. Data was analyzed both descriptively and through correlation analysis to test the study hypotheses. The key study findings were that in terms of usage rate, 98.4% of the installed energy efficient firewood cook stove (twin brick rocket) were generally in use although their usage was not entirely consistent. 20.6% of the households whose normal cooking routine was three times per day did not use the energy efficient stove every time they cooked. Also, 14% of the households cooked once per day on the energy efficient stove more than their normal cooking pattern of once per day. Significantly, 42.4% of the households still retained their old three stone open fire with 35.1% still in use. Besides, 21.6% of the households had other cooking devices which they simultaneously used. Regarding the factors that influence sustained usage of the energy efficient firewood cook stoves, the social and economic factors including the stove users' gender, age, education level, household size and monthly income had no significant influence as their respective significance level (P-values) equal to 0.443, 0.437, 0.464, 0.778 and 0.283 were above the $P \leq 0.05$ threshold. However, technological and cultural factors seemed to have influence on the efficient stove usage. Finally, the study showed that a single energy efficient firewood cook stove could save approximately 1.1315 tonnes of firewood translating to 1.4099 tonnes of CO₂e comprising 41.3% per year relative to the three stone open fire. The energy efficient stove remarkably reduces firewood consumption and GHGs emissions hence its sustained usage could have tangible impact on climate change mitigation. The overall conclusion was that despite the climate change mitigation benefits associated with the efficient stove's sustained usage, many households still inconsistently used it due to technological and cultural factors. The study recommends enhanced sensitization on the energy efficient stove's sustained usage benefits and scaling up its adoption.

TABLE OF CONTENTS

Content	Page
DECLARATION.....	ii
PLAGIARISM STATEMENT	iii
DEDICATION.....	iv
ACKNOWLEDGEMENT.....	v
ABSTRACT.....	vi
TABLE OF CONTENTS	vii
LIST OF FIGURES	xiv
LIST OF TABLES	xvi
LIST OF APPENDICES	xvii
LIST OF ACRONYMS	xviii
OPERATIONAL DEFINITION OF TERMS AND CONCEPTS	xxi
CHAPTER ONE: INTRODUCTION.....	1
1.1 Background to the Study.....	1
1.2 Statement of the Problem.....	5
1.3 Overall objective.....	7
1.4 Specific objectives	7

1.5 Research Question for specific objective 1	7
1.6 Hypotheses for specific objectives 2 and 3	8
1.7 Justification of the Study	8
1.8 Scope of the study	9
CHAPTER TWO: LITERATURE REVIEW	11
2.1 Global Biomass Energy Consumption and Situation.....	11
2.2 Biomass Energy Consumption and Situation in Sub-Sahara Africa (SSA).....	12
2.3 Biomass Energy Consumption and Situation in Kenya	14
2.4 Energy Efficient Cook Stove Program in Kenya	16
2.5 Types of Firewood Cook Stoves in Kenya	18
2.5.1 Three Stone Open Fire	18
2.5.2 Fixed Biomass Stoves	20
2.5.2.1 Rocket Stoves.....	20
2.5.2.1.1 The Twin Brick Rocket Stove.....	22
2.5.2.2 Jiko Kisasa or Maendeleo Jiko	23
2.5.3 Improved Artisanal Portable Firewood Stoves	24
2.5.3.1 Upesi/Kuni Mbili Jiko.....	24
2.5.4 Branded Firewood Stoves	25
2.5.5 Gasifier Firewood Stoves.....	26
2.6 Sustained Usage of Energy Efficient Firewood Cook Stoves	27

2.7 The Sociocultural, Economic and Technological Factors Influencing Usage of the Energy Efficient Cook Stoves.....	30
2.7.1 Sociocultural Factors Influencing Usage of the Energy Efficient Cook Stoves.....	31
2.7.1.1 Gender.....	31
2.7.1.2 Age of the main cook.....	32
2.7.1.3 Household Size	32
2.7.1.4 Education level of the main cook.....	33
2.7.1.4 Cultural Beliefs and Practices.....	34
2.7.2 Economic Factors Influencing Usage of the Energy Efficient Cook Stoves.....	35
2.7.2.1 Household Income	35
2.7.2.2 Price and Cost of the stove.....	36
2.7.3 Technological Factors Influencing Usage of the Energy Efficient Cook Stoves	37
2.7.3.1 The stove design	37
2.7.3.2 Stove fuel availability	37
2.8 Environmental Benefits of the Energy Efficient Firewood Cook Stoves.....	38
2.9 Determination of the Relationship Between Sustained Usage of the Energy Efficient Firewood Cook Stoves and Climate Change Mitigation	41
2.11 Conceptual Framework.....	47
CHAPTER THREE: MATERIALS AND METHODS	50
3.1 The study area.....	50

3.2 The Research Design	53
3.2.1 Descriptive Design.....	53
3.2.2 Experimental Design.....	53
3.3 The Target Population.....	55
3.4 Sampling Procedure and Sample Size Determination	55
3.4.1 Household Questionnaire Respondents	56
3.4.2 Kitchen Performance Test (KPT) Participants	58
3.4.3 Key Informant Interviewees	59
3.5 Data Collection	60
3.5.1 The Use of Questionnaires.....	60
3.5.2 Semi-Structured Key Informant Interviews.....	60
3.5.3 Data Collection in the Kitchen Performance Test	61
3.5.4 Validity and Reliability of the Data Instruments	62
3.6 Data Analyses	63
3.6.1 Quantitative Data Analyses.....	63
3.6.1.1 Measuring the Relationship between Sustained Stove Usage and Climate Change Mitigation.....	64
3.6.2 Qualitative Data Analysis	70
3.7 Ethical Considerations	70
3.8 Limitations of the Study.....	71

CHAPTER FOUR: RESULTS AND DISCUSSION.....	73
4.1 The Study Response Rate	73
4.2 Characteristics of the Survey Respondents.....	73
4.2.1 Gender of the respondents	73
4.2.2 Age of the respondents.....	75
4.2.3 Education level.....	76
4.2.4 The household size of the respondents	77
4.2.5 Household income of the respondents	77
4.3 The Usage Rate of the Firewood Cook Stoves	78
4.3.1 The Usage Rate of the Energy Efficient Firewood Cook Stove	78
4.3.1.1 The Frequency of the Energy Efficient Firewood Cook Stove Usage.....	81
4.3.1.2 Reasons for the Energy Efficient Firewood Cook Stove’s Inconsistent Usage....	84
4.3.2 The Usage of Three Stone Open Fire (TSOF).....	86
4.3.2.1 Reasons for Using the Old Three Stone Open Fire.....	89
4.3.3 Other Cooking Devices’ Usage	91
4.3.3.2 The Other Cooking Devices Usage Frequency.....	93
4.4 Factors that Influence Sustained Usage of the Energy Efficient Firewood Stoves by Households in Siaya County.....	95
4.4.1 Sociocultural Factors Influencing Usage of the Energy Efficient Cook Stoves.....	95
4.4.1.1 Gender and stove usage	95
4.4.1.2 Age and stove usage.....	97

4.4.1.3 Education level and stove usage	98
4.4.1.4 Household Size	100
4.4.1.5 The households' cooking practices and culture	101
4.4.2 Economic Factors Influencing Usage of the Energy Efficient Cook Stoves	103
4.4.2.1 Average Household Income and Stove Usage	103
4.4.2.2 Cost of the energy efficient stove and usage frequency	105
4.4.3 Technological Factors Influencing Usage of the Energy Efficient Cook Stoves ..	106
4.4.3.1 Stove Design and efficiency	106
4.4.3.2 Improved air quality in the kitchen	108
4.4.3.3 Fuel Availability	111
4.4.4 Testing the Hypothesis for Objective 2	114
4.5 The Relationship Between Sustained Usage of the Energy Efficient Firewood Cook Stoves and Climate Change Mitigation	114
4.5.1 Comparative Firewood Consumption	115
4.5.1.1 Firewood consumption by three stone open fire	115
4.5.1.2 Firewood consumption by the energy efficient firewood cook stove (twin brick rocket)	116
4.5.1.3 Savings on the Firewood Consumption	117
4.5.2 Comparative CO ₂ e Emissions	119
4.5.2.1 CO ₂ e Emission Reduction (ER)	120
4.1.3 Testing the Hypothesis for Specific Objective 3	121

CHAPTER FIVE: SUMMARY, CONCLUSIONS AND RECCOMENDATIONS	124
5.1 Summary of the Study Findings	124
5.1.1 The Usage Rate of the Energy Efficient Firewood Cook Stove in Relation to the Other Stoves in Siaya County	124
5.1.2 The Sociocultural, Economic and Technological Factors that Influence Sustained Usage of the Energy Efficient Firewood Cook Stoves by Households in Siaya County	126
5.3 Recommendation	129
5.2.1 Recommendation for further research	130
REFERENCE	131

LIST OF FIGURES

Figure 2.1: Three stone open fire.....	17
Figure 2.2: Twin brick rocket cook stove promoted by Tembea.....	20
Figure 2.3: Improved Ceramics (<i>Upesi/Kuni Mbili Jiko</i>).....	22
Figure 2.4. Jiko-Dura by Ecozoom and SmartSaver wood Jiko by Envirofit AMJ.....	23
Figure 2.5: The Hifadhi cook stove	24
Figure 2.6: Operational Conceptual Framework of the study.....	42
Figure 3.1: Map of Siaya County showing the study area	45
Figure 4.1: Gender of the respondents.....	61
Figure 4.2: Age of the respondents.....	62
Figure 4.3: Education level of the respondents.....	63
Figure 4.4: Household income of the respondents.....	64
Figure 4.5: Reasons for using the twin brick rocket stove.....	66
Figure 4.6: Normal cooking pattern compared with the energy efficient stove usage frequency.....	67
Figure 4.7: Stove usage frequency across the stove ages	69
Figure 4.8: Reasons for not consistently using the twin brick rocket cook stove.....	71
Figure 4.9: Old three stone open fire presence in the households	72
Figure 4.10: Reasons for using the three stone open fire.....	74
Figure 4.11: The other cooking devices used in the households	77
Figure 4.12: Frequency of the other cooking devices usage.....	78

Figure 4.13: The energy efficient stove usage by gender	81
Figure 4.14: The energy efficient stove usage by age	82
Figure 4.15: The energy efficient stove usage by education level.....	83
Figure 4.16: Circumstances under which old three stone open fire is still used.....	85
Figure 4.17: The energy efficient stove usage frequency based on household income....	87
Figure 4.18: The efficient stove users' satisfaction with the cost related factors	89
Figure 4.19: The stove users' satisfaction with design, overall quality and usage experience	90
Figure 4.20: Improved air quality in the kitchen and efficient stove usage frequency.....	92
Figure 4.21: Main fuel used for cooking by the households.....	93
Figure 4.22: How the households acquire firewood	94
Figure 4.23: Firewood collection sites for the households	94
Figure 4.24: The mode of firewood acquisition and energy efficient stove usage frequency.....	95

LIST OF TABLES

Table 3.1: Summary of the adopted design and data analysis per objective	47
Table 3.2: Sample distribution table for household survey	49
Table 3.3: Sample distribution table for KPT participants	50
Table 4.1: The study response rate	60
Table 4.2: Average household size	63
Table 4.3: The twin brick rocket energy efficient firewood cook stove usage rate	65
Table 4.4: Old three stone open fire usage in the past two weeks	73
Table 4.5: Households with other cooking devices	76
Table 4.6: Social factors and the energy efficient stove usage	80
Table 4.7: Household income and the energy efficient stove usage	88
Table 4.8: Analyzed sample for the KPT	97
Table 4.9: Firewood consumption by the energy efficient cook stove and TSOF	100
Table 4.10: Firewood usage by the energy efficient stove and TSOF	101
Table 4.12: Calculated NonCO ₂ Emission Factor of the fuel	103
Table 4.13: Parameters used to quantify the CO ₂ e emissions	105
Table 4.14: Smoke emission by the energy efficient stove and TSOF	107
Table 4.15: Relationship between the energy efficient cook stove usage, fuel consumption and less smoke emission	108

LIST OF APPENDICES

Appendix I: Household Questionnaire.....	136
Appendix II: Kitchen Performance Test (KPT) Questionnaire	144
Appendix III: Key Informant Interview (KII) Schedule.....	146

LIST OF ACRONYMS

ACCES	– Africa Clean Cooking Energy Solutions
AMJ	– Artisanal Metal Jiko
BC	– Black Carbon
BEIA	– Biomass Energy Initiative for Africa
CBO	- Community Based Organization
CCAK	– Clean Cooking Association of Kenya
CCT	– Controlled Cooking Test
CDM	- Clean Development Mechanism
CO	– Carbon Monoxide
CO ₂	– Carbon Dioxide
CO ₂ e	– Carbon Dioxide Equivalent
DPS	– Department of Postgraduate Studies
EAC	– East African Community
EFwood	- Emission Factor of Wood
EPA	– Environmental Protection Agency
ER	- Emission Reduction
FC	– Fuel Consumption
GACC	– Global Alliance of Clean Cookstoves
GHGs	– Greenhouse Gases
GIZ	– German Development Agency
GoK	– Government of Kenya

GS – Gold Standard

GWP - Global Warming Potential

ICS – Improved Cook Stove

IPCC – Intergovernmental Panel on Climate Change

KNBS – Kenya National Bureau of Statistics

KPT – Kitchen Performance Test

LPG – Liquefied Petroleum Gas

MMUST – Masinde Muliro University of Science and Technology

MtCO₂e – Metric Tons of Carbon Dioxide Equivalent

NACOSTI - National Commission for Science, Technology and Innovation

NCV_{wood} - Net Calorific Value for wood

NMHCs – Non-Methane Hydrocarbons

NRBf - Non-renewable biomass fraction

OC – Organic Carbon

ODK – Open Data Kit

PICs – Products of Incomplete Combustion

SCG – Siaya County Government

SCIDP – Siaya County Integrated Development Plan

SDGs – Sustainable Development Goals

SE4All – Sustainable Energy for All

SEI - Stockholm Environment Institute

SeTAR - Sustainable energy Technology and Research

SLCFs – Short Lived Climate Forcers

SPSS – Statistical Package for Social Sciences

SSA – Sub Sahara Africa

SUMS - Stove Usage Monitoring System

TaTEDO - Tanzania Traditional Energy Development Organization

TSOF – Three Stone Open Fire

UCT – Uncontrolled Cooking Test

UN – United Nations

UNDESA – United Nations Department of Economic and Social Affairs

UNEP – United Nations Environment Programme

UNICEF - United Nations International Children's Emergency Fund

USAID – United States Agency for International Development

VCS – Verified Carbon Standard

WBA - World Bioenergy Association

WBT - Water Boiling Test

WEC – World Energy Council

WHO – World Health Organization

WMO – World Meteorological Organization

OPERATIONAL DEFINITION OF TERMS AND CONCEPTS

Baseline cook stove – The main cook stove that existed in or was being used by the households prior to adopting the energy efficient cook stove.

Carbon dioxide equivalent (CO_{2e}) - The number of metric tonnes of carbon dioxide (CO₂) emissions with an equivalent global warming potential (GWP) as one metric tonne of another greenhouse gas (GHG).

Climate change - Long-term alteration of weather patterns regarded as a potential result of the greenhouse effect, manifested mainly through increasing global atmospheric temperature and storm activity.

Climate change mitigation – The process of reducing the flow of heat-trapping greenhouse gases into the atmosphere by either cutting the greenhouse gases emission or enhancing the greenhouse gases sinks to absorb and store these gases.

Consistent stove usage – stove being used every time the household is cooking, as per the household's cooking routine.

Energy efficient firewood cook stove – A cook stove with high rate of combustion and heat transfer, reduces firewood consumption and releases less emissions in comparison to traditional three stone open fire

Firewood – Any wooden material, seasoned or heat treated (dry) but not heavily processed, used for fuel.

Greenhouse gas – A gas that absorbs or traps radiation thereby contributing to the heating of the earth's surface, for example, carbon dioxide (CO₂), nitrous oxide (N₂O), methane (CH₄), chlorofluorocarbons (CFCs), ozone (O₃), or water vapour (H₂O_(g)).

Long-term stove usage – stove being used throughout its lifespan, beyond the initial acceptance and use.

Stove stacking - The simultaneous use of multiple cooking devices by households in their cooking routine.

Sustained usage of energy efficient firewood stove – Consistent and long-term usage of the adopted energy efficient firewood stove.

Three stone open fire - A cook stove set up using three stones of equal heights to balance a cooking pot over the fire.

Tortillas - A thin, unleavened bread, circular in shape that is made from wheat flour or maize hominy meal and cooked on a pan without applying oil.

Twin brick rocket cook stove – An energy-efficient firewood cook stove made out of bricks and good clay soil, with two separately fired cooking units, designed to reduce firewood consumption and smoke emission.

Ugali - A bread locally made in Kenya from corn, sorghum or millet flour, whose cooking pot needs to be held firmly when being prepared.

CHAPTER ONE

INTRODUCTION

1.1 Background to the Study

Climate change is a serious global crisis that could internally displace over 200 million people by 2050 (de Almeida Saraiva, 2023). The important role that using energy efficient firewood cook stoves could play in climate change mitigation through reduction in anthropogenic greenhouse gases (GHGs) emissions and fuel consumption is gaining wide acknowledgement. Solid biomass fuels including firewood burned on inefficient cook stoves emit greenhouse gases (GHGs) and short-lived climate forcers (SLCFs) also referred to as products of incomplete combustion (PICs), contributing to climate change (Floess *et al.*, 2023).

Globally, about 3 billion people comprising 40% of the global population rely on solid biomass fuels to meet their basic cooking energy demand (Floess *et al.*, 2023; Samad & Portale, 2019). Whereas considerable variations exist in different regions and sectors based on the technologies and types of fuels used as well as local cooking practices, developing countries in Africa and Asia where most households still use inefficient cooking devices, are generally recognized as dominant source regions of cooking related GHGs and PICs emissions (Gustafsson *et al.*, 2009).

In most parts of the Sub Sahara Africa (SSA), over 80% of the rural households including 900 million people, rely on firewood mainly burnt on three-stone open fire to meet their demands for cooking energy (Akakpo *et al.*, 2024; Bensch, Jeuland & Peters, 2021; Nzengya, Maina & Njeru, 2021). In Kenya, for instance, solid biomass fuels like firewood provide the overall cooking energy requirements to between 75% and 80% of the

approximately 8 million households (Schiefer, 2021; Otieno, 2019; Mbaka, Gikonyo & Kisaka, 2019). Significantly, over 90% of the populations in rural parts of Kenya use the polluting solid biomass fuels. In Siaya County for instance, between 84.2% and 98% of households have been reported to inefficiently use wood fuel for cooking (Schiefer, 2021; SCG, 2018; Okoyo, 2017).

Bensch *et al.* (2021) observes that despite the optimistic suppositions about electricity and liquefied petroleum gas (LPG) dissemination, increasingly emphasized by the global policy discourse, emissions related with the solid biomass fuels might evolve until 2050 in SSA. Bensch *et al.* (2021) further argues that massive investments in infrastructure, that might also take considerable amount of time to materialize, will be required to establish a dependable electricity and LPG supply across the Global South.

The foregoing, coupled with increasing population growth and urbanization in the region, might result in substantial increase in demand for biomass energy thereby exerting much pressure on forests and resulting in increased emissions (Nzengya *et al.*, 2021; Johnson & Chiang, 2015). Here, interventions that enhance access to improved or cleaner cooking technologies are greatly needed (CCAK, 2019). The use of energy efficient cook stoves remains a good transitional solution (Samad & Portale, 2019). Garg *et al.* (2010) also observed that for the economically underdeveloped villages with very limited access to modern fuels, improved cook stoves present a desirable option.

Consequently, there have been efforts to substitute the traditional inefficient biomass stoves with more energy efficient improved solid biomass stoves to curb the inefficient biomass stoves' negative impacts (Karanja & Gasparatos, 2019; Kapfudzaruwa, Fay & Hart, 2017). The improved cook stoves (ICS) can significantly reduce the climate-forcing

emissions, substantially mitigating the climate change (Bensch *et al.*, 2021). The global platform for facilitating access to modern energy for all by 2030, Sustainable Energy for All (SE4All), identifies clean cooking as one of its high impact opportunities (Rogelj, McCollum & Riahi, 2013).

Notably, access to modern and sustainable energy has taken centre stage in the international policy discourse, being enshrined in the Sustainable Development Goal (SDG7) aiming at “ensuring universal access to affordable, reliable, sustainable and modern energy for all by the year 2030” (General, 2015). Adoption and sustained usage of clean energy fuels and technologies will partly be used to measure progress towards the achievement of SDG7 (Karanja & Gasparatos, 2019). A report by Clean Cooking Association of Kenya indicates that by shifting to clean and efficient cooking solutions as a means to climate change mitigation, the Kenya government is projecting an abatement potential of 7.3 Mt CO_{2e} by 2030. The report further notes that using clean cooking solutions is expected to significantly support efforts by the Kenya Government to attain the desired 10% forest cover (CCAK, 2019).

Kenya is seen as one of the pioneers in developing, marketing and distributing clean cook stove in SSA (CCAK, 2019). Numerous stove and fuel options have been made available to Kenyan consumers through a strong policy push by the government and numerous initiatives by local and international organizations. Whereas about 80% of the Kenyan households still inefficiently burn woody biomass for their household energy needs, the Kenya clean cooking sector has shown some levels of improvement in adoption rate (Karanja & Gasparatos, 2019; Kapfudzaruwa *et al.*, 2017). The interventions have helped to either commercially or under carbon market schemes produce, import and disseminate

the different types of clean cook stoves and fuels in the Country (CCAK, 2019; Practical Action, 2010).

In Siaya County, the government, international and local NGOs have been promoting improved cook stoves for some time now. The organizations have supported local artisans to design, assemble and disseminate the energy efficient stoves in the county. In particular, Tembea Youth Centre for Sustainable Development (Tembea) has over the last thirteen years, since 2010, installed about 127,242 twin brick rocket stoves (used as the reference energy efficient firewood cook stove in this study) in the Siaya households under its *energy efficient cook stove for Siaya Communities carbon offset project*. This implies that of the 250,698 households in Siaya (KNBoS., 2019), about 50% had access to an energy efficient firewood cook stove.

That almost half of the households in Siaya accessing energy efficient firewood cook stoves notwithstanding, the expected environmental benefits including climate change mitigation in the County can only be fully realized with the stoves' sustained long-term usage (Samad & Portale, 2019). Understanding the effect of long-term usage of energy efficient firewood cook stoves on climate change mitigation seems to have received little attention not only in Siaya County but Kenya and the SSA region. Previous studies conducted in Siaya County focused more on the improved cook stoves' adoption determinants and energy consumption (Otieno, 2019; Okoyo, 2017).

This study bridged the existing knowledge gap by evaluating the effect of sustained usage of energy efficient firewood cook stoves on climate change mitigation in Siaya County. The study went beyond just determining the stoves' usage rates but also identified and

analyzed the sociocultural, economic and technological circumstances under which the stove's sustained usage could occur or not. The study was premised on the understanding that sustained usage of the energy efficient firewood cook stoves is expected to occur in a dynamic system with intricately linked interactions between the sociocultural, economic and technological contexts. The study also made efforts to quantify the effect of sustained usage of energy efficient firewood cook stoves on climate change mitigation in Siaya County.

1.2 Statement of the Problem

The importance of using energy efficient firewood cook stoves for reducing anthropogenic GHGs and PICs emissions as well as firewood consumption is fast gaining wide acknowledgement. In Siaya County, given the limited supply of modern energy carriers and over-dependence on locally available biomass fuels, improved cooking devices had been promoted and disseminated by both the national and Siaya County government, in collaboration with international and local NGOs working in the County, in many households in the County to cut on firewood consumption and GHGs emissions. However, the expected environmental benefits including climate change mitigation in the County could only be fully realized with the stoves' sustained long-term usage (Samad & Portale, 2019).

Effect of sustained usage of energy efficient firewood stoves on climate change mitigation remained unclear and lowly researched in Siaya County. There existed a knowledge gap because the link had not been clearly established between the adopted stoves' sustained usage (stove being used consistently throughout its lifespan, beyond the initial acceptance

and usage) and climate change mitigation.

Previous studies in the area (Otieno, 2019; Okoyo, 2017) had mainly focused on the factors influencing initial adoption of improved cooking stoves and energy consumption more than the adopted stoves' sustained usage. Significantly, the studies associated the adoption more with acceptance and initial use rather than their sustained usage. While the studies provided insights into the determinants of initial uptake of the stoves, there was still knowledge gap on the determinants of the stoves' sustained usage.

Noteworthy, the studies that had focused on the stoves' usage were conducted in contexts different from that of Siaya and with different stove designs and fuels. In fact, none of the reviewed studies in Siaya had linked sustained usage of the stoves to climate change mitigation. Particularly, the studies had not documented the adopted stoves' usage rates in terms of the proportion of the households using the improved stoves long after their adoption in relation to those who continued to use their old stoves or other cooking devices in the County. However, it is through this knowledge that the anticipated environmental benefits of the stoves could be quantified.

Also, whereas studies by Otieno (2019) and Okoyo (2017) respectively established the social, economic and spatial factors influencing stoves' adoption in the County, their results conflict with those of some of the studies conducted elsewhere. Moreover, the studies only adopted descriptive research designs and were respectively conducted in a single Sub-County and Ward, making their generalization to the entire County context difficult. Against this background, this study that adopted both descriptive and experimental designs (mixed research method), determined the adopted stoves' usage

rates, evaluated the factors influencing their sustained usage and established the relationship between the stoves' sustained usage and climate change mitigation in Siaya County.

1.3 Overall objective

To evaluate the effect of sustained usage of energy efficient firewood cook stoves on climate change mitigation in Siaya County, Kenya.

1.4 Specific objectives

- i. To determine the usage rate of the energy efficient firewood cook stove (twin brick rocket) in relation to the other stoves used by the households in Siaya County.
- ii. To evaluate sociocultural, economic and technological factors that influence sustained usage of the energy efficient firewood cook stoves by households in Siaya County
- iii. To determine the relationship between sustained usage of the energy efficient firewood stoves by households and climate change mitigation in Siaya County.

1.5 Research Question for specific objective 1

- i. What is the usage rate of the energy efficient firewood cook stove (twin brick rocket) in relation to other stoves used by the households in Siaya County?

1.6 Hypotheses for specific objectives 2 and 3

- i. H₀: There is no significant influence of the sociocultural, economic and technological factors on sustained usage of the energy efficient firewood cook stoves by households in Siaya County.
- ii. H₀: There is no significant relationship between sustained usage of the energy efficient firewood cook stoves by households and climate change mitigation in Siaya County

1.7 Justification of the Study

The study findings would hopefully be useful source of information to policy makers, researchers, the energy efficient cook stoves promoters and the local communities. For the policy makers, understanding the relationship between the sustained usage of energy efficient firewood cook stoves and climate change mitigation would inform the intervention steps especially on policy discourse around quantification of carbon credits generated based the improved stoves usage as well as formulating policies that are cognizant of the socio-cultural, economic and technological factors that influence the improved stoves sustained usage.

Researchers would benefit from the new and additional knowledge generated by this study on the effect of sustained usage of energy efficient firewood cook stoves on climate change mitigation and could conduct further research on the areas recommended for such by this study. Also, the energy efficient cook stove promoters would learn the opportunities and challenges around the sustained usage of the energy efficient cook stoves to be able to adopt the best practices in their stoves' promotion work. Generally, the study would help

advance the society's understanding and appreciation of the contribution of sustained usage of energy efficient firewood cook stoves by households to climate change mitigation.

1.8 Scope of the study

The study only evaluated the effect of sustained usage of energy efficient firewood cook stoves on climate change mitigation in Siaya County, Kenya. The study was limited to firewood as the main fuel hence Siaya County was a suitable site for the study since the main source of the Siaya County households' cooking fuel is firewood. The firewood is predominantly used on traditional three stone open fire although some households already adopted energy efficient firewood cook stoves including twin brick rocket.

While all the types of cook stoves used by the sampled households were analyzed, the twin brick rocket stove relative to the three stone open fire, was the one used to determine the relationship between the sustained usage (over the stove's lifespan) of energy efficient firewood cook stove and climate change mitigation. The twin brick rocket stove was chosen because it had been widely and systematically disseminated in the Siaya rural households between 2011 and 2023 compared to the other energy efficient firewood cook stoves and the list of beneficiaries was available.

The study sampled households where the twin brick rocket stove had been disseminated by Tembea between 2011 and 2023 (over the 13 years period) within Siaya County. The energy efficient firewood cook stove (twin brick rocket) had been disseminated within households in five out of the six Sub-Counties of Siaya County including Ugenya, Ugunja, Alego-Usonga, Gem and Rarieda. These households had the requisite experience and knowledge to be able to address the research questions.

The effect of sustained usage of the energy efficient firewood cook stove on climate change mitigation was only measured through changes in firewood consumption and the associated CO₂e emissions resulting from the usage of the energy efficient firewood cook stove in comparison to the three stone open fire. Whereas reduced firewood consumption due to sustained usage of the energy efficient firewood cook stove was expected to augment climate change mitigation by improving tree cover (enhancing carbon sink), this study did not consider the related vegetation cover changes noting that factors other than extraction of firewood, which the promoters of the energy efficient firewood cook stoves sought to address in the County, could lead to tree cover loss.

CHAPTER TWO

LITERATURE REVIEW

2.1 Global Biomass Energy Consumption and Situation

While dependence on solid biomass including firewood varies across individual nations of the world, it remains the dominant source of energy in both the developed and developing countries (ExCo, 2021). Due to its natural availability and adaptability to both small-scale and large-scale uses such as cooking in households and industrial heating, biomass energy is a preferred energy resource (Kurchania, 2012). As of 2019, solid biomass sources supplied 85% of the global domestic energy (World Bioenergy Association, 2020) with firewood accounting for 68% of the total global biomass energy mix (Otieno, 2019). In 2020, global fuel wood production stood at 1.93 billion cubic metres with Africa and Asia each contributing 37%, being the highest of the global share (Aso *et al.*, 2023).

The use of biomass fuels is at its highest levels in China, India and many of the developing countries and may continue to rise in the foreseeable future. In Asia for instance, more than 80% of the Nepal's population relies on solid biomass such as firewood for basic cooking and lighting (Benti *et al.*, 2021). Global projections in energy infrastructure trends show that as many as 1.4 billion people will still rely on biomass by 2030 (Bogale & Wondogenet, 2020). This implies a considerably great demand for fuel wood by the 2030, a disturbing trend given the current shortage in its supply (Adhola, 2014). The growing numbers of poor rural households who heavily depend on firewood for their cooking needs coupled with the expanding energy-dissipative economic activities are some of the drivers of the global demand for biomass fuel (Benti *et al.*, 2021).

The extraction and use of biomass fuels remains a significant part of the global forest biomass loss through deforestation and degradation of forest which by extension causes disruption of local ecosystem services and exacerbates CO₂ emissions into the atmosphere (Dissanayake *et al.*, 2018). However, some studies like Kar and Keles (2016), agree that using biomass energy could bring environmental benefits including decreased pressure on the non-renewable energy resources such as fossil fuels thereby reducing emission of greenhouse gases. They further note that biomass energy can sustain an economically beneficial productivity value chain, significantly contributing to government revenue through taxes and income generation to the people involved.

But this position is disputed by other studies like Smith *et al.* (2000) who found out that the contribution of a meal cooked using biomass to global warming can be significantly higher when compared to the one cooked using fossil fuels, depending on the examined timeline. Black carbon resulting from biomass fuels burned while cooking is believed to be a key driver of climate change (Bond *et al.*, 2013). Unless deliberate efforts are put in place to adopt and consistently use improved stoves to cut on the demand on solid biomass fuel and reduce GHGs emissions, there are likely to be serious negative implication on climate change mitigation across the world.

2.2 Biomass Energy Consumption and Situation in Sub-Sahara Africa (SSA)

Biomass energy resources including firewood and charcoal supply about 81% of Sub-Saharan African (SSA) households with primary energy for cooking (Akakpo *et al.*, 2024; World Bank, 2011). Particularly, in Countries like Kenya, Tanzania, Uganda and Rwanda 80% of households still depend on non-clean energy sources (Mbaka *et al.*, 2019). This

level of over-dependence on biomass energy in SSA is far greater than in any other regions of the world and is likely to remain at this very high level or grow to even higher levels over the coming few decades (Namaswa *et al.*, 2022). In the face of an increasing economic development coupled with high population growth and strong urbanization there is bound to be a growing demand for energy in the region (World Bank, 2011).

Whereas about 1.7 billion people is estimated to use wood fuel and other biomass fuel in Asia between 2000 and 2030, the numbers in Africa is expected to rise by more than 40% during the same period (Adhola, 2014), potentially exposing vast, once highly productive areas of tropical forests in terms of biomass yield, to complete depletion (Coelho, Karekezi & Lata, 2012). This further portends a bleak future for a region already grappling with serious challenges of high deforestation and land degradation (Richard, 2012). Using the example of Ethiopia where about 88% of forest wood fuel harvests are considered non-renewable, Dissanayake *et al.* (2018) argues that the highest rate of deforestation in the world, due to wood fuel use, is experienced in SSA.

Unfortunately, other cleaner sources of energy including electricity, required to meet additional energy needs, may not provide suitable alternatives for cooking given the associated high costs (Bildirici & Özaksoy, 2016). Generally, progress towards realizing universal access to sustainable energy is still quite slow in SSA. In fact, the lowest electricity access rate is and will continue to be experienced in the SSA region inhabited by about two-third of the world population living without electricity (Akakpo *et al.*, 2024). A study by UN Environment Programme (UNEP) launched in 2019 at the 17th African Ministerial Conference on the Environment in Durban, South Africa, reported that by 2050

over 65% of the sub-Saharan Africa's population will still be relying on woodfuel for cooking.

The way biomass energy resources are traditionally used and managed in SSA region remains unsustainable and breaches many of the biomass sustainability indicators (Akakpo *et al.*, 2024). The urgent need for greater investments in appropriate bioenergy technologies to provide a paradigm shift from traditional to sustainable bioenergy technologies cannot be overemphasized. UNEP, during the 17th African Ministerial Conference on the Environment in Durban, South Africa, called for urgent action towards addressing the biomass energy production and consumption challenges in Africa. That despite the tremendous efforts being made by African nations towards achieving the global energy goals by 2030, the region still needs urgent action to tackle the unsustainable biomass energy use to minimize its negative impact on the environment and human health (UNEP, 2019). Sustained usage of energy efficient firewood cook stoves provides one of the viable options for averting the negative environmental and human health impacts in the SSA.

2.3 Biomass Energy Consumption and Situation in Kenya

Energy is one of the foundations of the Country's development blue print, the Kenya Vision 2030. The development of new energy sources is prioritized in the vision, to not only reduce the high energy costs but also to increase efficiency in energy consumption (Karekezi, Kimani & Onguru, 2008). However, just like in many other Sub-Sahara African Countries, biomass energy resources remain the main sources of energy supply in Kenya (Karanja & Gasparatos, 2020). By supplying 10,771 kilotons of energy (ktoe) per annum, accounting for about 68% of the Kenya's energy supply, biomass energy makes up the

largest share (Takase, Kipkoech & Essandoh, 2021; Mbaka *et al.*, 2019; Waris, 2017). Firewood is the dominant biomass energy used by over 80% of the Kenyan rural households (Otieno, 2019). The local usage rates vary from this national average. In Siaya County, for instance, the County Integrated Development Plan for 2018-2022 indicates that firewood is used for cooking in at least 84.2% of the households (SCG, 2018). Even higher figures have been reported for Siaya by other studies (Schiefer, 2021; Okoyo, 2017) that as much as 98% of the households inefficiently use wood fuel for cooking contributing significantly to national GHG emissions.

In Kenya, biomass fuel supplies are obtained from woodlands, enclosed forests, grasslands, bushlands and farmlands (Takase *et al.*, 2021). The widespread use of biomass energy in the Country has implications on the natural resources' sustainable utilization, especially forests that are threatened with degradation. The imbalances between demand and supply of the biomass energy places tremendous strain on the land usage in terms of agriculture and forestry, worsening the land depletion processes (Coelho *et al.*, 2012). According to the Kenya Forest Service (2013), sustainability of the biomass energy resources can be ensured by shifting to a more efficient production and use system from the current uncontrolled biomass energy consumption and production. Adopting technologies that minimize wood fuel consumption are needed more than ever to make utilization of the wood fuel sustainable.

Energiewende *et al.* (2015) observes that the progress of Kenya as a Country in the promotion of household level clean energy consumption has had its own share of challenges leaving nearly three-quarter of the Kenyan population with no option but to depend on biomass sources in meeting their needs for cooking, heating and lighting. A key

factor for the biomass energy consumption in the Country is rapid population increase coupled with limited access to renewable energy alternatives (Takase *et al.*, 2021).

The portion of households that depend on non-clean energy was projected to rise by 73% from 26 million in 2015 to 45 million in the year 2020 (Energiewende *et al.*, 2015). The energy consumption behaviour, apart from negatively impacting the Country's climate change mitigation efforts, hinders overall growth of the Kenyan economy and the overall household level welfare benefits. The indoor pollution arising from the exposure to biomass smoke negatively impacts human health. Close to 15,000 lives from households whose energy use revolves around biomass are lost annually in Kenya, with women and girls being the most affected (Berkouwer & Dean, 2019).

2.4 Energy Efficient Cook Stove Program in Kenya

In response to the UN conference on the new and renewable energy sources, the development and promotion of the efficient stoves in Kenya dates back to the 1980s. Initially developed to address the energy crisis, the energy efficient biomass stoves quickly got recognition as a promising alternative, beneficial to both climate and human health through reduction of emissions and fuel consumption (Odongo, 2017). Consequently, the Kenyan government and her development partners, different donors including non-governmental organizations and some private sector players have been developing and promoting the energy efficient cook stoves in Kenya (Basu, James & Maret, 2016; Puzzolo *et al.*, 2013). Working in collaboration with the Kenyan Ministry of Energy, some of the pioneer organizations that spearheaded the development and dissemination of the stoves in the Country include GIZ, Practical Action, Bellerive Foundation, USAID and UNICEF

(CCAK, 2019). Under the programs like the Kenya Renewable Energy Program as well as Women and Energy Project, training and technical assistance were provided to local artisans to help develop, design, produce, import, assemble and disseminate the stoves in the Country (Practical Action, 2010). Through a strong policy push and numerous local and international initiatives several stove and fuel alternatives have been made available to Kenyan consumers under either commercial or carbon market schemes (Samad & Portale, 2019).

Kenya is seen as one of the pioneers and role model in developing, marketing and distributing clean cook stove in SSA (CCAK, 2019; Winrock International, 2011). The energy efficient cook stove program in Kenya owes its success to being part of the global initiatives including the Global Alliance of Clean Cook stoves (GACC) that sought to see 100 million households adopt clean and efficient cook stoves and fuels by 2020 (Samad & Portale, 2019; Putti *et al.*, 2015). Also, the energy efficient cook stove program in Kenya benefited from the World Bank's Biomass Energy Initiative for Africa (BEIA) launched in 2010 to modernize the biomass energy sector in SSA (World Bank Group, 2015). Furthermore, the Kenyan energy efficient cook stove program got a boost from the Africa Clean Cooking Energy Solutions (ACCES), a market-transformation program launched in 2012 by the World Bank to scale up the adoption of energy efficient technologies through enterprise-driven approaches in SSA (World Bank *et al.*, 2015).

However, the performance of the energy efficient cook stoves programs still attracts divergent opinions. Some studies report that the Kenya clean cooking sector has shown some levels of improvement in adoption rate (Kapfudzaruwa *et al.*, 2017; Practical Action, 2010). According to the proponents, training of the local artisans to design, produce and

disseminate the stoves has resulted to increased production and demand. That training the small-scale producers has leveraged the supply side while awareness and marketing campaigns have intervened on the demand side by helping establish sustainable local markets for the stoves (Martin *et al.*, 2011; Teodoro, 2008). The opponents, on the other hand, argue that the energy efficient cook stoves adoption rates are still relatively low as about 80% of the households in Kenya still inefficiently burn woody biomass for their household energy needs (Karanja & Gasparatos, 2019). That despite the over four decades of promotion, the households have not yet settled on an ideal universally accepted energy efficient biomass cook stove in the Country (Silk *et al.*, 2012).

2.5 Types of Firewood Cook Stoves in Kenya

Different types of firewood cook stoves exist in Kenya as described in the following sections.

2.5.1 Three Stone Open Fire

Three stone open fire (TSOF) is a cook stove set up using three stones of equal height to balance a cooking pot over the fire lit directly on the ground (Mapelli & Mungwe, 2013). While it is the simplest, cheapest and widely used stove, especially in the developing countries, its use has attracted a lot of criticism. A number of concerns have been raised against TSOF. First, using TSOF leads to high fuel consumption (Hafner *et al.*, 2018) as heat generated per unit of fuel is not much, fraction of the generated heat directed to the pot is small and only a small proportion of the heat directed to the pot is passed on into the food (Khan, Hossain, & Rahman, 2016). Second, slow pace of cooking is experienced while using the TSOF since less heat is transferred to the pot and about 90% of the energy

generated from open fires is lost to the environment especially in windy conditions (GIZ, 2018; Hudelson, Bryden & Still, 2002). Third, TSOF produces a lot of smoke with negative environmental and health impacts (Hawley & Volckens, 2013). In an open fire, the combustion tends to be incomplete as oxygen hardly gets to where it is most needed. This coupled with low temperatures, results to low thermal and combustion efficiency (Preble *et al.*, 2014). Fourth, is exposure to fire accidents since the flames are not shielded so the items around can easily catch fire (Beahrs, 2013). It is the limitations of the TSOF that majority of the emerging improved stove designs have focused to address by sinking and insulating the stove combustion chamber to improve its thermal and energy efficiency and minimize emission (Nyankone, 2018).

Nonetheless, there are TSOF users who see positive side of some of the associated inefficiencies. First, some of the users feel it is convenient to use TSOF if other household chores have to be done alongside cooking as open fires burn slowly hence do not require a lot of attention (Hafner *et al.*, 2020). Second, while the smoke produced by TSOF negatively impact environment and health, it can help control mosquitoes, which is particularly beneficial in areas highly infested with the malaria vector. Also, the smoke can be useful for preservation of food stuff. Third, light emitted by open flames helps when there is darkness and heat lost into the environment is favorable for heating in cold weather or areas (GIZ, 2018).



Figure 2.1: Three stone open fire

Source: Solar Cookers International (2021).

2.5.2 Fixed Biomass Stoves

Unmovable stoves with improved thermal efficiency compared to the three stone open fire. Fixed biomass stove may vary from stone and concrete cooking areas to those integrating ceramic liner and chimney. Common examples in Kenya include Rocket stoves and *Jiko kisasa* or *Maendeleo* stoves (MoE, 2019).

2.5.2.1 Rocket Stoves

Invented by Dr. Larry Winiarski, rocket stove remains one of the most successful stove designs used in developing countries (Hudelson *et al.*, 2002). Rocket stoves are known to use less fuel and produce less smoke compared to TSOF due to their higher combustion

efficiency. A study by Ochieng, Vardoulakis and Tonne (2013) that compared traditional three-stone stoves and rocket mud stoves (RMS) in rural Kenya showed that use of RMS led to a 33% reduction of carbon monoxide produced in the kitchen during cooking. Rocket stoves can help conserve wood by over 60% and their efficiency rate surpasses the *Jiko Kisasa* by almost 20% (Kamfor, 2002). According to (GIZ, 2018) and Khan *et al* (2016), the rocket stoves achieve their efficiency by working under a principle characterized by:

- i. A combustion chamber fitted with a fuel wood shelf to facilitate the pre-drying of the firewood and enable a controlled and adequate movement of primary air that is warmed while it passes under the wood through to the burning tips of the firewood.
- ii. A combustion chamber tall enough to behave like a chimney, capable of generating more draught way above a standard stove. The tall chamber allows more time for the gases and particles to burn completely to be able to emit all their heat with carbon dioxide and water vapour as the main discharge. The air and fuel particles and volatiles are mixed in the process to produce a hot flame.
- iii. An insulated internal wall that prevents loss of heat to the stove body by reflecting all the heat back into the combustion chamber. The insulation makes the chemical reaction more intense and keeps the combustion chamber very hot.
- iv. A well-defined gap between a 'skirt' and the pot, that allows the hot flue gases to pass through, forcing a large percentage of the heat against the sides of the pot thereby transferring the heat to the pot. Where various sizes of pot are used on the same stove, the skirt can be funnel-shaped to accommodate different pots, although some efficiency will be lost.

2.5.2.1.1 The Twin Brick Rocket Stove

The energy efficient twin brick rocket stove promoted by Tembea is designed for burning firewood and consist of two units for cooking, that can be fired separately. The stove is installed in a fixed position in the households' kitchen or cooking area. The size of the stove depends on the size of the sauce pan (pot) to be used in cooking. Locally available materials such as anthill soil, bricks and sawdust are used in the construction of the stove (GIZ, 2018). Local artisans (especially young women) identified from the villages are trained on the stove construction and mobilization of the households targeted with the stove. Regular climate education and energy demonstration are carried out to strengthen environmental awareness as well as the stove adoption and utility (Practical Action, 2010).

The energy efficient twin brick rocket firewood cook stove is believed to bring several benefits to the users. It cooks fast and brings down firewood consumption by approximately 40-60% thereby lessening the burden of firewood gathering on women and children or relieving the households' expenditure on fuel. The stove produces less smoke, experienced only when being lit considerably improving indoor air quality. The stove is affordable since it is made from locally available materials and can be used for over 7 years if properly maintained (GIZ, 2018).

The stove was being promoted under a carbon offset project dubbed “Energy *Efficient Cook Stove for Siaya Communities*” (UNFCCC, 2013) implemented in partnership with a Zurich based Foundation *Myclimate*. Between October 2010 to October 2023, Tembea had installed some 127,242 twin brick rocket stoves in the rural Siaya households found in Ugenya, Ugunja, Alego-Usonga, Gem and Rarieda Sub-Counties. Tembea is a registered

grassroots community-based development non-profit organization based in Siaya County and focused on community empowerment, environment stewardship and innovating community development processes to eradicate poverty.



Figure 2.2: Twin brick rocket cook stove promoted by Tembea

Source: Tembea (2023).

2.5.2.2 Jiko Kisasa or Maendeleo Jiko

Jiko Kisasa also known as *Maendeleo Jiko* is a fixed, inbuilt household stove with one or two potholes. The stove has a single continuous fuel feed, with no firewood shelf, and an independent firewood chamber for each pot. The stove is fitted with a ceramic liner (a fired clay product) which serves as a lining for the fire chamber. The right material and proper

tools and techniques should be used to make the chamber lining (ceramic liner) in order to achieve the required combustion quality. The stove body can be made of anthill soil, normal clay or good red soil. The stove is without a chimney and can be designed to accommodate different pot sizes (Nyankone, 2018).

Under the leadership of the Kenyan Ministry of Energy, the stove was first developed in the the Country in the late 80's by different players including GIZ, leaning institutions like universities and local potters. Based on Controlled Cooking Test (CCT), the stove saves up to 40% of firewood compared to the three stone fire, if used properly with dry firewood (GIZ, 2018; Orlale & Odee, 2013).

2.5.3 Improved Artisanal Portable Firewood Stoves

Improved artisanal portable firewood stoves are variants of the artisanal metal jikos (AMJ) that use firewood instead of charcoal. The portable firewood stoves are made by enclosing the clay or ceramic liner, for improved thermal efficiency, in a metallic container. In Kenya, the most dominant type of improved artisanal portable firewood stove is the *Upesi* or *Kuni mbili* stove (Njogu, 2011).

2.5.3.1 Upesi/Kuni Mbili Jiko

Upesi jiko is a simple ceramic liner produced locally in Kenya. The production guided by the standards which aim to retain the correct shape and size for the maintenance of energy-saving efficiency in the design. *Upesi jiko* has its ceramic liner cladded in metal sheet. It has one pothole, a single fuel feed door and can accommodate different pot sizes (Njogu, 2011).



Figure 2.3: Improved Ceramics (*Upesi/Kuni Mbili Jiko*)

Source: Njogu (2011).

2.5.4 Branded Firewood Stoves

These are standardized and factory based improved portable firewood stoves. Some manufacturers brand their fire wood stoves for quality assurance and guaranteed performance. Examples of familiar stove brand names include *Kuni Okoa* by BURN manufacturing company, *Dura* by EcoZoom Crunchbase company and *Supersaver* wood stove by Envirofit International.



Figure 2.4. Left: Jiko-Dura by Ecozoom. Right: SmartSaver wood Jiko by Envirofit AMJ

Source: Infonet Biovision (n.d).

2.5.5 Gasifier Firewood Stoves

Gasifier firewood stoves can be both portable and stationary. A gasifier burns biomass under controlled oxygen, making wood gas and charcoal by burning the volatiles and tars. The used energy results from the gas mixture and charcoal (Njenga *et al.*, 2015). A gasifier has three parts comprising a gas combustion chamber which is 15cm high at the top, in the middle is a 22cm high fuel container, and at the bottom is a 6cm high air inlet. As a gasifier gets ignited at the top, primary air enters at the bottom and moves up through the packed fuel. Secondary air enters from below into the top section, where it mixes with the gases for combustion (Njenga *et al.*, 2016).

An improved Hifadhi cooking stove is an example of a portable gasifier locally produced, distributed and used by Kenyan households. The Hifadhi stove has two compartments comprising an air entrance at the bottom with a space for fuel and a combustion chamber on top. The inner walls are made of cement enclosed by galvanized steel (Njenga *et al.*, 2015).



Figure 2.5: The Hifadhi cook stove

Source: Njenga et al. (2015).

2.6 Sustained Usage of Energy Efficient Firewood Cook Stoves

In this paper sustained usage of energy efficient firewood stove implies consistent and long-term use of the adopted energy efficient firewood stove throughout its lifespan, beyond the initial acceptance and use. In reality, energy efficient cook stoves adoption may not imply their continuous usage by the households (Kapfudzaruwa *et al.*, 2017). Studies have recommended research on the extent of use of energy efficient cook stoves in rural households (Tebugulwa, 2015). Jeuland, Soo and Shindell, (2018) concurs that sustained usage of energy efficient cook stoves has proven elusive. Gill-Wiehl, Kammen and Haya (2023) analyzed carbon offset cook stove projects registered under the Gold Standard (GS)

and Verified Carbon Standard (VCS) registries and reported a 48% sustained usage rate for the adopted stoves.

The implication of these studies is that most households may not necessarily consistently use their energy efficient stoves after the initial adoption. Studies (Prah *et al.*, 2021; Bensch *et al.*, 2021; Hoigt, 2019; Sundararaman *et al.*, 2016; Ruiz-Mercado *et al.*, 2011) agree that the sustained usage of improved cook stoves by households is expected to occur in a dynamic system with intricately linked interactions between the stove technologies (design, efficiency, fuel sources/availability, and cost), cooking practices, the users' awareness and perceptions, as well as the wider social, economic and ecological contexts making it a complex matter. That other studies have also established generally low adoption rates of the improved cook stoves ranging from 12.3% (Adane, 2020), 30% (Jagger, 2019) to 38.5% (Karanja & Gasparatos, 2020) is even more worrying in the face of climate change if the few adopted stoves cannot be used consistently.

Various theoretical models had been used previously to describe issues around adoption and sustained usage of improved cook stoves by households. One of the theories is the fuel switching also known as energy ladder theory (Ruiz, 2012). Climbing the energy ladder entails shifting from traditional energy inefficient cook stoves to more energy efficient stoves at household level (Osiolo, 2021). The energy ladder theory holds that households will entirely replace their traditional cooking devices with energy efficient alternatives as soon as they overcome their income and access constraints. The theory places more emphasis on income as the key driver of household's stove choice (Massera *et al.*, 2000). That once the income status allows for the stove acquisition, households switch and rely on only the new cooking device. The theory further posits that complete substitution of the

traditional cooking devices results from the households' consideration of the new cooking device to be better than the traditional one for all their cooking tasks, based on the energy efficiency ratio.

However, Puzzolo *et al.* (2013) observes that there are more other factors aside from income and the stove technology that influence adoption and sustained usage. Hence, complete substitution of traditional cooking devices with modern stoves is not always the case as use of multiple cooking devices has been documented as the norm in many households (Joon *et al.*, 2009). The stove stacking theory has therefore been used to explain the use of multiple cooking devices by households. The stove stacking theory has guided studies on stove adoption and sustained usage to focus on the whole cooking system by considering the dynamic interaction between users, stoves, fuels and the wider socioeconomic contexts. As opposed to wholly relying on the simplistic fuel switching approach, the possibility of partial substitution of the cooking devices has been taken into account.

The other theory that explains the technology adoption process is the Diffusion of Innovation theory by Rogers (1995), cited in Tebugulwa (2015). The diffusion of innovation theory explains how and why innovations emerge, get into use and widely spread or not. According to this theory, the innovation adoption decision is a five staged mental process comprising knowledge, persuasion, decision, implementation and confirmation. The theory asserts that whereas the diffusion of an innovation is a technical matter, it is just as much a social one, with several factors affecting the transition between these five different stages. The decision-making unit including socio-economic and

personality characteristics affect the knowledge stage. The innovation's perceived characteristics comprising its relative advantage, complexity, triability, observability and compatibility affect the persuasion stage. That, if the innovation is perceived as one that has relative advantages, is not overly complex, can be tried on a limited basis, can offer observable results, and is compatible with existing practice and values then an increased rate of the technology dispersion will be experienced.

A number of previous studies trying to understand the uptake of improved cook stoves have drawn from the diffusion of innovations theory. For instance, Ruiz-Mercado (2012), apart from incorporating theoretical contributions from other authors like Shih and Venkatesh (2004) and Dearing (2009), drew on the diffusion of innovation theory to propose a new framework for understanding cook stove adoption and sustained use. The framework by Ruiz-Mercado (2012) presents the adoption of a new cooking device as a dynamic complex process and a stage in the larger process of technology absorption and cultural adaptation.

2.7 The Sociocultural, Economic and Technological Factors Influencing Usage of the Energy Efficient Cook Stoves

Factors influencing the adoption and usage of improved cook stoves can be broadly categorized into social, economic and technological factors (Odongo, 2017). In this paper, the social factors comprise the demographics including gender, age, household size and education level of the main cook. The economic factors include household income and the cost of the stove (affordability). Technological factors include the stove design, efficiency and fuel availability.

As described in the subsequent sections, there seemed to be no unanimous agreement as to whether these factors influence adoption and usage of improved cook stoves or not. While some studies have revealed that these factors determine adoption and usage of the improved stoves by households, others have concluded that there is no relationship between the factors and the stoves' adoption and usage. This study will seek to give further insights on the influence of these factors or lack of it, on the usage of energy efficient firewood cook stoves in Siaya County, Kenya.

2.7.1 Sociocultural Factors Influencing Usage of the Energy Efficient Cook Stoves

2.7.1.1 Gender

Power relations in a household, cooking responsibilities and cultural norms are some of the gender related influences on the adoption and usage of improved biomass cook stoves (Vigolo *et al.*, 2018). For married couples, important household expenditure decisions including the purchase of an improved cook stove, lies with the husbands (Van der Kroon, Brouwer & Van Beukering, 2014). However, it is the women who have been culturally assigned the role of cooks in their households, making them the primary users of the cooking technologies hence the primary bearers of the negative effects associated with using inefficient cooking devices (World Health Organization, 2016). The burden of collecting or in some instances buying fuel wood needed for cooking is borne by the women. The women end up spending disproportionately long hours in dangerous fuel wood collection areas where they get exposed to the risk of gender-based violence such as rape and physical assault for allegedly trespassing into private properties (Clancy *et al.*, 2012). Furthermore, the women are constrained in terms of time to pursue other

productive ventures that can result into generation of income for their household (Carr & Hartl, 2010). Significantly, households headed by a female are more likely to adopt and use improved cook stoves as a study by Brooks *et al.*, (2016) established.

2.7.1.2 Age of the main cook

A study by Clark *et al.* (2017) demonstrated that age inhibits the household's switching to cleaner and efficient cooking devices, and the older the main cook is the more likely he/she will stick to their old way of cooking. The study affirmed that households headed by younger people show a greater likelihood of adopting and using the improved cook stoves. Vigolo *et al.* (2018) further argues that the influence of age on the adoption and usage of the improved cook stoves is closely linked with the gender of the household head and age becomes a barrier when the household head is a male aged over 55 years. However, a study by Jan *et al.* (2017) found no correlation between the age of the household head and the adoption and use of improved cook stoves. Similarly, Lewis and Pattanayak (2012) found a negative relationship between the age of the household head and the adoption and usage of improved cook stoves.

2.7.1.3 Household Size

Household size can be defined in terms of the total number of adults and children living under the same roof or those whose basic needs such as food, shelter and clothing are provided for by a single benefactor (Vigolo *et al.*, 2018). The United Nations Department of Economic and Social Affairs (UNDESA) categorizes households consisting of fewer than three people as small and those consisting of more than five people as large (UNDESA, 2017). The average household size in Kenya is four members with smaller

households consisting of one to two members standing at 31.2 % (KNBS, 2018).

Household size may or may not influence the adoption and usage of improved cook stoves as previous studies have found negative, positive or zero correlation between household size and the adoption and use of improved cook stoves. A study in India by Mohapatra and Simon (2017) reported a negative correlation between household size and adoption of improved cook stoves. According to the study, large families did not adopt or use improved cook stoves because it was difficult preparing meals for large families using small cook stoves. Also, a study by Nyandie (2017) in Busia Kenya, cited in Otieno (2019), observed smaller households to be adopting and using improved cook stoves. Other studies, on the other hand, have found household size not to have an influence on the adoption and usage of improved cook stoves. A study by Mamuye *et al.* (2018) in Dodola Ethiopia, for instance, demonstrated that household size had no influence on the adoption and usage of improved cook stoves for there was no significant difference in the mean household size of users and non-users of the improved cook stoves.

2.7.1.4 Education level of the main cook

Previous studies have associated higher levels of education with positive adoption and usage of improved cook stoves. A study by Wilson *et al.* (2016) in Darfur Sudan concluded that households headed by people with educational achievements consistently used improved cook stoves. Kong'ani *et al.* (2019) linked the observed low rate of adoption and usage of improved cook stoves with the corresponding low levels of formal education in Kiambu, Kenya. Similarly, Jan *et al.* (2017) observed that household heads with primary or secondary level of education had a higher chance of adopting and using

improved cook stoves in rural Pakistan. Vigolo *et al.* (2018) posits that regardless of the gender, education consistently determines adoption and usage of improved cook stoves. That the more educated the household head is, the more the household would use cleaner cooking technologies (Pundo *et al.*, 2006).

Yet still, some studies have reported that household head's education level does not influence adoption or usage of improved cook stoves. For example, Troncoso *et al.* (2007) argue in a study conducted in rural Mexico that rather than the number of years they spent in school, it is the early adopters' open mindedness and progressiveness that influenced adoption and usage of a particular type of improved cook stove. Likewise, a study in rural Tanzania by Kulindwa *et al.* (2018) observed a negative correlation between adoption and usage of improved cook stoves and household head's level of education.

2.7.1.4 Cultural Beliefs and Practices

According to Muwanga, Mwiru and Watundu (2023) socio-cultural practices are habitual activities and rituals including various simple to complex routine behaviours. In the context of energy efficient cook stove adoption and sustained usage, socio-cultural practices denote habitual and ritual activities that potentially influence the households' choice of cooking devices. Previous studies have linked the persistent use of traditional cooking devices with cultural beliefs and practices. A study by Njau and Matto (2024) in Arumeru District, Tanzania assessed the socio-cultural factors influencing the choice of improved cooking stove technology among agro-pastoral communities and found out that some socio-cultural practices encouraged the persistent use of traditional three-stone stoves over improved stoves. Some of the practices that this community found valuable

but immensely contributed to high biomass fuel consumption included preferences for food cooked on traditional three stone open fire and the tradition of handing over the traditional stoves to a woman newly married in the household. Similarly, Akintan, Jewitt and Clifford (2018) argue that in Nigeria traditional norms and taboos influence fuel choice and cooking practices than the lived realities of exposure to harmful emissions from the use of traditional cooking stoves. Moreover, cooking smoke was considered useful by the Nigerian households.

2.7.2 Economic Factors Influencing Usage of the Energy Efficient Cook Stoves

2.7.2.1 Household Income

Household income can play both as a barrier and enabler for the adoption and usage of improved cook stoves. When a household is unable, from its disposable income, to purchase an improved cook stove, then the household income is considered a barrier. If, on the other hand, the household can still purchase an improved cook stove from its disposable income alongside meeting basic needs, the household income then becomes an enabler (Vigolo *et al.*, 2018). Pine *et al.* (2011) noted that compared with non-adopters, adopters of improved cook stoves in rural Mexico had higher income levels. Onyeneke *et al.* (2019) also concurs by observing similar trend in River State Nigeria that households using an improved cook stove had higher income compared to those not using the stoves.

According to Vigolo *et al.* (2018), apart from higher levels of income enabling households to use improved cook stoves, it also gives them the option to simultaneously adopt and use other forms of clean cooking energy like electricity and liquefied petroleum gas. As the income increases, households gradually shift from low level fuels like firewood to

higher level cleaner fuels like Liquefied Petroleum Gas (LPG) and electricity. Households with high level of income that stick to using firewood, preferably use it on improved cook stoves with greater cooking efficiency (Vitali & Vaccari, 2014). Although some studies have reported that income has no influence on the adoption and usage of improved cooking devices in households. Nyandie (2017) cited in Otieno (2019), for instance, observed a negative correlation between income and use of improved cook stoves.

2.7.2.2 Price and Cost of the stove

Price of the improved cook stoves can influence households' progression in the energy transition ladder. Low prices have been observed to encourage transition to cleaner and more efficient cooking technologies while increase in the stove prices reverse the gains made (Kar & Zerriffi, 2018). According to Kulindwa *et al.* (2018) a percentage rise in the price of improved cook stoves led to reduced stove purchases in rural Tanzania. In Kenya, given the low-income levels of most households, improved cook stoves' affordability has been identified as a major barrier to their use (Stevens *et al.*, 2020). The same is the case in Ethiopia where a study by Mamuye *et al.* (2018) found that the price of an improved cook stove, considered to be expensive by household heads, was the reason they were not using the stoves. However, studies that have investigated the influence of prices of alternative fuels such as LPG on the adoption and usage of improved cook stoves have concluded that there is a negative relationship (Lewis & Pattanayak, 2012).

2.7.3 Technological Factors Influencing Usage of the Energy Efficient Cook Stoves

The stove technology related characteristics including design (efficiency, size, and

reparability) and fuel availability could influence the stoves' adoption and usage.

2.7.3.1 The stove design

The uses a stove can be put to, its durability, repair and maintenance costs if any and the ease with which any parts can be replaced comprise its design (Rehfuess *et al.*, 2014). Shen *et al.* (2014) observes that a stove design that addresses fuel saving needs and performs multiple tasks including space heating and cooking significantly influences its adoption and usage by households.

2.7.3.2 Stove fuel availability

Improved cook stove adoption and usage can be influenced by fuel availability. For fuel obtained at a cost, households would preferably use cooking technologies that achieve higher cooking efficiency with minimal fuel usage (Jagger & Jumbe, 2016). Households that obtain fuel at no cost, mostly by gathering and collection, tend not to be keen at using efficient cooking technologies (Mamuye *et al.*, 2018). The cost and accessibility of fuel determine its availability. Noteworthy, opinion is varied as to the exact influence of fuel availability on adoption and usage of improved cook stoves. While some studies show that fuel availability positively influences adoption and usage of improved cook stoves, others find negative relationships or no effect at all (Vigolo *et al.*, 2018).

2.8 Environmental Benefits of the Energy Efficient Firewood Cook Stoves

Usage of energy efficient firewood cook stoves brings beneficial environmental outcomes such as reduced GHGs emissions and firewood consumption (Bensch *et al.*, 2021). Traditional cooking devices like three stone open fire, on the other hand, are highly

inefficient since they are incapable of either controlling combustion or optimizing heat transfer (Grieshop, Marshall & Kandlikar, 2011). Using the inefficient cook stoves emits GHGs and other products of incomplete combustion (PICs) that include gaseous non-methane hydrocarbons (NMHCs) and carbon monoxide (CO) as well as particulate black carbon (BC) and organic carbon (OC) substances (Malla & Timilsina, 2014). The smoky solid cooking fuels are known to contribute about 2% (1 gigaton of CO_{2e} every year) of global GHGs emissions and 45% of the emissions is attributed to cooking with firewood on three-stone open fires (Gill-Wiehl *et al.*, 2023; Samad & Portale, 2019). Also, about 26% of global BC emission (the strongest light-absorbing component of particulate matter), originates from combustion of biomass for cooking (Malla & Timilsina, 2014; Bond, 2009). These PICs continue to receive serious attention and are considered climate forcers with significant influence on the climate system (Floess *et al.*, 2023; UNEP & WMO, 2011).

Many stove programs have focused on addressing fuel shortages by reducing fuel use and the associated negative environmental impacts, mainly deforestation, by improving the stoves' thermal efficiency as well as reducing emissions through increased combustion efficiency (Bond, 2009). Improved energy efficient cook stoves address the problem of GHGs and PICs emissions through increased thermal efficiency and reduced specific emissions. According to Grieshop *et al.* (2011), the energy efficient cook stove's increased thermal efficiency - the product of combustion efficiency and heat transfer efficiency - reduces cooking fuel requirement. The improved combustion efficiency reduces specific PIC emissions per fuel used or food cooked and with the help of a confined combustion

chamber and intensified contact between the heated gases, the improved cooking vessels achieve heat transfer efficiency.

Diverting to improved cook stoves could significantly lower total greenhouse gas (GHG) emissions (World Bank, 2010). Based on a report by Clean Cooking Association of Kenya, clean and efficient cooking solutions as a means to climate change mitigation presents an abatement potential of 7.3 MtCO_{2e} by 2030 for Kenya (CCAK, 2019). In India, Venkataraman *et al.* (2010) argues that adopting improved stoves could bring down the Country's overall greenhouse gas (GHG) emissions by 4%, worth in excess of \$1 billion on the global carbon market. Stockholm Environment Institute (SEI, 2013) estimates the global potential for GHG emission reductions from improved cook stove projects at 1 gigaton of CO_{2e} per year. According to Kandlikar *et al.* (2009), for every dollar spent to switch to an improved stove, benefit of between \$100 and \$880 of CO_{2e} accrues, with the cost effectiveness of improved stoves standing at about \$4 per ton CO_{2e}.

The ability of improved cook stoves to reduce GHGs such as CO₂ and some PICs emissions has been used as the foundation for their incorporation in carbon offset projects. However, being considered complex and short-lived climate forcers (SLCFs) with varied climatic effects distinguishing them from long-lived GHGs like CO₂, the PICs such as BC, CO and NMHCs have not been included in the current climate agreements and offset schemes (Grieshop *et al.*, 2011). The PICs' immensity of the net climate warming or cooling is not yet fully clear, necessitating further research and quantitative assessment (EPA, 2012), but their dramatic global and regional impacts continue to become more of a concern (Ramanathan & Carmichael, 2008). Addressing cooking related PICs and GHGs emissions continue to garner renewed attention as a measure towards climate change mitigation

(Grieshop *et al.*, 2009). The additional impetus for improving the cook stoves is given by the strong belief that curbing emissions from household fuel use presents a low-risk means for addressing the acute climate impacts of PICs like BC, manifested through monsoon rainfalls disruption and rapid melting of glaciers (Kandlikar *et al.*, 2009). Meanwhile, the Intergovernmental Panel on Climate Change (IPCC's) 2018 Special Report on Global Warming of 1.5°C, indicates that the world has until 2030 to cut the anthropogenic carbon dioxide (CO₂) emissions by half to realize a 50% chance of forestalling the worst climate change consequences (Allen *et al.*, 2019).

Unsustainable utilization of biomass for cooking is regarded a major contributor to deforestation, a particular environmental concern in developing countries. The East African Community, for example, records that as of 2006 annual deforestation rate of 3-4% in Kenya, 2% in Tanzania and 2% in Uganda was attributable to heavy dependence on biomass (EAC, 2006). Using clean cooking solutions is expected to significantly support efforts by the Kenya Government to attain the desired 10% forest cover (CCAK, 2019). In Peru's Chalaco District and its environs, forest research by Ektvedt (2011) strongly related fuelwood collection to cutting down trees from cloud forest areas, constituting the main cause of forest degradation in the areas. On the contrary, some studies have revealed that biomass used for cooking, mainly fuelwood, is not the major reason for deforestation globally (Arnold *et al.*, 2003). DeFries and Pandey (2010) examined relationships among urbanization, household energy source and forest cover in India and found out that as much as fuelwood demand may lead to local degradation, it does not lead to large-scale deforestation.

The use of cooking technologies that achieve higher combustion efficiency and minimal fuel usage by households, especially in Africa and Asia, remain a central part of the climate change mitigation and environmental conservation efforts. However, an energy efficient cook stove technology by itself is not enough solution without the cook stove being correctly and consistently used over a long period of time (Samad & Portale, 2019). Cook stove implementation program should therefore take into consideration and respect the local cooking styles and roles, food types and fuel supplies to enhance the stoves adoption and sustained usage (Treiber, 2012).

2.9 Determination of the Relationship Between Sustained Usage of the Energy Efficient Firewood Cook Stoves and Climate Change Mitigation

The relationship between sustained stove usage and climate change mitigation can be determined by measuring the stoves' capacity to reduce fuel consumption and the associated GHGs emissions. A number of laboratory and field-based methodologies have been developed to help assess cook stove performance in this regard. The frequently used methods for testing cook stoves performance are Water Boiling Test (WBT), Controlled Cooking Test (CCT) and Kitchen Performance Test. Both WBT and CCT are laboratory-based cook stove performance tests while KPT is a more field-based method. Through KPT the daily fuel consumption by stoves, used in normal household environment, can be measured and consumption rate compared among the tested stoves. Besides measuring fuel consumption, KPT is a field-based method that can measure other broader issues including stove acceptability using both quantitative and qualitative household surveys (Bailis, Smith & Edwards, 2007). WBT is a technical method that involves using a standard pot to boil

and simmer water in a systematic and repeatable way (Bailis *et al.*, 2007). For CCT a local representative meal is cooked many times under controlled conditions (Bailis, 2004).

Each of the stove performance testing methods have their strengths and limitations as they vary in terms of the extent of repeatability, accuracy, costs, location and applicability to a cooking system's real world scenarios. For instance, WBT can generate repeatable results since it is carried out under controlled laboratory conditions but the results may not necessarily be reflective of how the stove could perform in the household (Taylor, 2009). KPT can provide a more real view of household level stove performance but the findings could be limiting as the results are more aggregated and prone to a high degree of variation (Bailis, 2018). Likewise, through CCT a representative and repeatable result could be achieved by many times cooking the exactly same meal but may still leave out key cooking system behaviour depending on the choice of the prescribed meal's cooking method, required quantities of fuel and food types (Johnson *et al.*, 2010).

To help address the limitations associated with the CCT and KPT, a new methodology called Uncontrolled Cooking Test (UCT) has been proposed by the University of Johannesburg's Sustainable energy Technology and Research (SeTAR) Centre (Robinson, Ibraimo & Pemberton-Pigott, 2011). The proponents of UCT argue that it could help better understand a cooking system's performance over a widely ranging variables. With UCT the cook is allowed, without being constrained in any way, to prepare a meal of choice and in own way of cooking. The only measurement taken during the UCT is the mass of the food cooked and firewood used. In this way UCT is able to capture a profile of stove

performance across a range of conditions thereby giving a more representative data set that could help better measure variabilities inherent in real world cook stove users' behaviour and fuel options. UCT is structurally different from the other task-based assessments like CCT which is interested in repeatedly analyzing a single task of cooking a specific meal. In comparison with the KPT, UCT arguably offers a more rapid and cost-effective means for assessing a new cooking technology's energy savings, whether under a development programme or a carbon off-set scheme (Robinson *et al.*, 2011). UCT is however, still being developed and is yet to be fully recognized as a universally accepted stoves and fuel testing methodology.

KPT remains the dominant field based procedure for assessing household fuel consumption with a primary objective of quantifying the fuel consumption under typical household conditions. KPT normally takes between 3 to 7 days to accomplish, with daily stock take of the fuel consumption. KPT can be combined with household survey to help in contextualizing the fuel consumption practices. A carefully conducted KPT, complemented with general household survey, is the greatest way for understanding the impact of a stove on fuel consumption. However, the stove tester has to deal with the shortcomings of the KPT methodology. KPT may potentially intrude on the target households' daily cooking activities. Besides, KPT measurements could be more uncertain given the difficulty to control the sources of potential errors compared to the laboratory based tests like WBT or CCT.

According to Bailis *et al.* (2018), through KPT many different kinds of assessments could be accomplished. The KPT could be used to: show the variations in cooking fuels'

consumption between households using traditional cooking technologies and those adopting improved cooking technologies; evaluate household fuel consumption pattern resulting from improved stove interventions; assess seasonal variations in household fuel consumption emanating from climatic changes, available fuel options and prevailing agro-economic trends; test fuel consumption differences among households using different fuel types on similar stoves; and test fuel consumption changes that are not a direct result of using a particular stove technology.

KPT can be done by adopting either a *paired-sample* study or a *cross-sectional* also referred to as *independent* study (Standard G., 2021). In a paired-sample study, the fuel consumption by both the traditional (baseline) stove and new improved (project) stove is tested for the same household. The test can first be done for the baseline stove and the one for the project stove done after some time when the households have started to use the new stove. In a cross-sectional or independent study, the test on fuel consumption by the stoves is done with different groups of households, one group using the traditional stove (control group) and the other using the new improved stove. Cross-sectional study can run simultaneously in the two sets of households.

Since both of the KPT designs, whether paired-sample or cross-sectional study, have their own advantages and disadvantages the design choice should be guided by its suitability or adaptability to the conditions of the stove users. While paired-sample study permits capturing of seasonal variations and changes in the performance of the stoves through repeated testing in the same households, it is not possible to test both the old and new stove

in the same household if the households have not adopted the new improved stove. Also, paired-sample design is time consuming. Moreover, changes in the prevailing weather or local economic conditions in the period between the tests with the traditional and new stove may affect fuel consumption. According to Bailis *et al.* (2018), the two tests in a paired-sample study should be timed in such a way that they happen during the same season to minimize the differences in weather condition. Additionally, the testers should be cognizant of the changes in any other factors including local economy that could potentially influence fuel nonconsumption.

Cross-sectional study, on the other hand, saves time as the tests with the traditional and new stove can be done simultaneously but variations in the households' socioeconomic or environmental conditions may influence fuel consumption in a manner that jeopardizes the results validity. Based on the recommendation by Bailis *et al.* (2018) and the existing target households' conditions, this study adopted the paired-sample study. The paired-sample KPT helped to assess fuel consumption by both the baseline stoves and project stove in the same household to determine the relationship between sustained usage of the energy efficient firewood cook stove (twin brick rocket) and climate change mitigation in Siaya County, Kenya.

2.10 The Research Gap

Most of the reviewed literature concur that unsustainable biomass energy consumption behaviour, apart from negatively impacting the climate change mitigation efforts, hinders overall growth of the economy and the household level welfare benefits. While the studies vouched for interventions that enhance access to improved or cleaner cooking

technologies, they focused more on the determinants of the improved cooking technologies' adoption and energy consumption by associating the adoption more with acceptance and initial use rather than sustained usage. Although the studies provided insights into the determinants of initial uptake of the stoves, the expected environmental benefits of adopting the cleaner cooking technologies could only be achieved with their sustained usage (Samad & Portale, 2019).

Understanding the effect of sustained usage of energy efficient firewood cook stoves on climate change mitigation seems to have received little attention from many of these studies. In fact, except Bensch *et al.* (2021) and Hoigt (2019) none of the reviewed studies linked sustained usage of the stoves to climate change mitigation. Noteworthy, the ones that focused on the stoves' usage (Prah *et al.*, 2021; Bensch *et al.*, 2021; Hoigt, 2019; Sundararaman *et al.*, 2016; Ruiz-Mercado *et al.*, 2011) were conducted in contexts different from that of Siaya and with different stove designs and fuels.

In summary there was knowledge gap relating to:

- i. The adopted energy efficient cook stoves' usage rates in terms of the proportion of the households using the improved stoves long after their adoption in relation to those who continued to simultaneously use their old stoves or other cooking devices in Siaya County.
- ii. The socio-cultural, economic and technological factors that influenced the sustained usage of the energy efficient cook stoves beyond their initial acceptance/adoption.
- iii. The link between the sustained usage of the energy efficient cook stoves and climate change mitigation in Siaya County.

2.11 Conceptual Framework

The study conceptual framework drew from the *Energy Ladder/Fuel Switching*, *Stove Stacking* and *Diffusion of Innovation* theories and considered the sustained stove usage as a product of the whole cooking system comprising the dynamic interaction between the users, stove technology, available fuels and the wider social, cultural and economic contexts. That the energy efficient stove's sustained usage (independent variable) could potentially be influenced by the households' sociocultural and economic together with the stove's technological characteristics.

Considering the sociocultural factors like gender, age, household size, education level and cooking practices in the evaluation was critical. Particularly, gender related issues including household power relations, cooking responsibilities and cultural norms where women are the primary users of the cooking technologies (with the greatest burden of collecting or in some instances buying fuel wood needed for the cooking) but it is the men that largely make energy efficient stove purchase decisions were pertinent. It was expected that a more educated household would use cleaner cooking technologies more. Likewise, a household with higher income was expected to afford and use a cleaner cooking technology more than the households with lower income.

Moreover, a stove design that achieve higher cooking efficiency with minimal usage of the available fuel could influence the stove's usage rate. It was the energy efficient cook stove's sustained usage that would have positive implications on climate change mitigation (dependent variable). The sustained usage was expected to result in less firewood consumption and reduced GHGs emissions, positively affecting climate change mitigation.

However, the relationship between the sociocultural, economic and technological factors and the sustained efficient stove usage could be moderated by the stove maintenance and repair services, available fuel options, climate change awareness and government policies on climate change mitigation and biomass energy consumption, as presented in Figure 2.5.

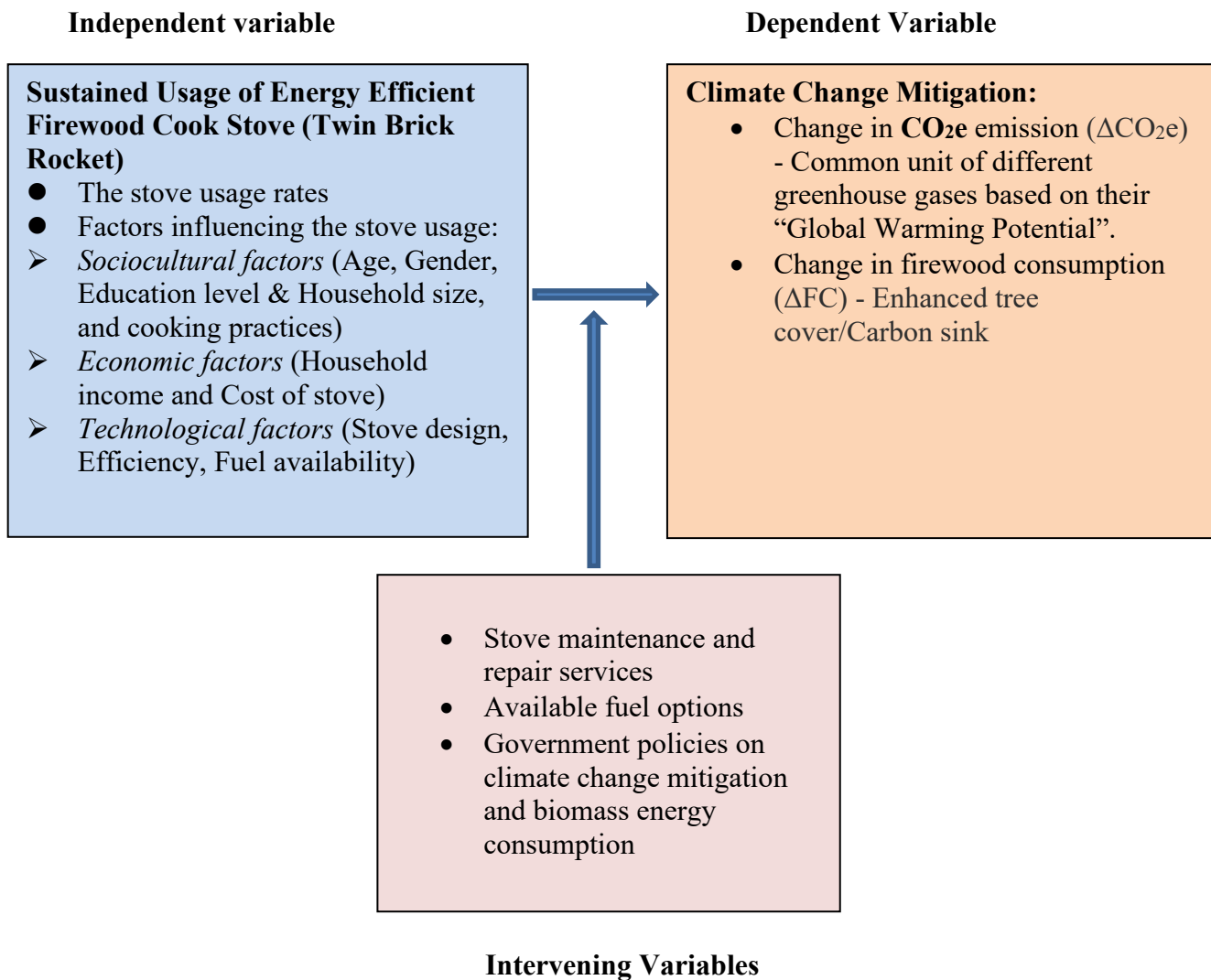


Figure 2.5: Operational Conceptual Framework of the study
Source: Researcher (2024).

CHAPTER THREE

MATERIALS AND METHODS

3.1 The study area

The study was conducted in five out of the six Sub-Counties of Siaya, Kenya, where the twin brick rocket energy efficient firewood cook stove had been disseminated, including Ugenya, Ugunja, Alego-Usonga, Gem and Rarieda. Siaya County has a land surface area of approximately 2,530km² and water surface area approximately 1,005 km². The County lies between latitude 0° 26' South to 0° 18' North and longitude 33° 58' and 34° 33' East. It borders Busia County to the North West, Vihiga and Kakamega counties to the North East, Kisumu County to the South East and Homa Bay County across the Winam Gulf to the South (SCG, 2018).

The 2019 population census by the Kenya National Bureau of Statistics established that the County has 250,698 households comprising a human population of 989,708 persons with a population density 396.50 persons per square kilometer and a crude birth rate (per 1000 population) that stands at 62.6. Given the high crude birth rate, the Siaya County population is bound to increase fast over the coming years, projected to hit 1,285,971 persons by 2030. Currently, the County has about 250,698 households with an average household size of about 4 members (KNBS., 2019).

According to the Siaya County Integrated Development Plan for 2018-2022 (SCG, 2018), the main sources of the households' cooking fuel included firewood (84.2%), charcoal (13.2%), LPG gas (1.1%) and paraffin (0.8%). The main cooking devices included traditional three stone (71.4%), ordinary jiko (10.8%), improved cook stove (14.5%), gas

cooker (2%), kerosene stove (0.6%) and electric cooker (0.07%). Similarly, Otieno (2019) examined the factors influencing use and adoption of clean cooking technologies in rural households in Bondo Sub-County of Siaya County and established that the households predominantly use biomass based solid fuels including firewood for their cooking needs.

With 0.42% forest cover, Siaya has the least forest cover out of the forty-seven counties in Kenya (Atieno, 2022). Notably, the County is reported to have lost about 14% of its tree cover between 2001 and 2022, equivalent to 1.30 Mt of CO₂e emissions (Global Forest Watch, n.d). The likelihood of prolonged over-dependence on the biomass energy resources in the County will further strain the already dwindling traditional supply sources in the County (Mugo & Gathui, 2010). If the business as usual scenario of heavily using the biomass energy resources on inefficient cook stoves continues, the efforts to achieve the 2010 Constitution's call for 10% tree cover may remain elusive in the County.

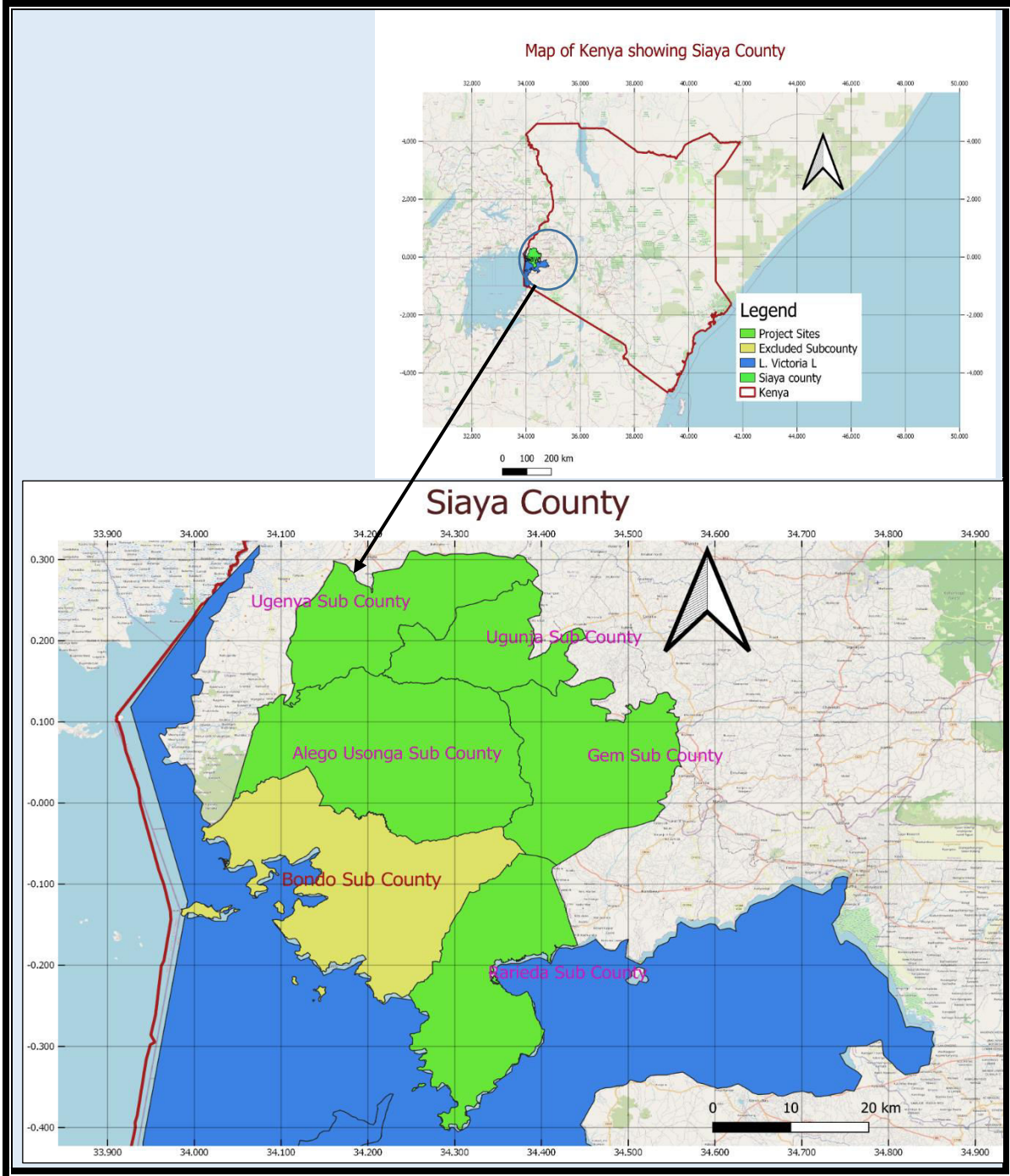


Figure 3.1: Map of Siaya County showing the study area

Source: Researcher (2024).

3.2 The Research Design

Both descriptive survey and experimental designs were adopted in the study.

3.2.1 Descriptive Design

The descriptive design was the most suitable for evaluating both the energy efficient firewood cook stoves usage rate (the first objective) and the social, economic and technological factors influencing sustained usage of the energy efficient firewood cook stoves in Siaya County (the second objective). The descriptive survey allowed for interviewing and administering of questionnaire (Harris & Brown, 2019) to a sample of the stove owners to collect information on their opinions, habits, attitudes, or any of the several social and economic issues (Kombo & Tromp, 2006). The design enabled recording, analyzing and reporting the state of affairs as it is (Ioannidis *et al.*, 2014)

3.2.2 Experimental Design

Experimental design was used to determine the relationship between sustained usage of the energy efficient firewood cook stoves and climate change mitigation (the third objective). The experiment followed the Kitchen Performance Test (KPT) protocols. The KPT adopted a **paired-sample** study (with no control) in which a comparison of the fuel consumption by the energy efficient firewood cook stove (twin brick rocket stove) and the old three stone open fire was done for the same household. The households sampled for this experiment was provided with a predefined quantity of firewood to use over a seven days period (Monday to Sunday) on their energy efficient firewood cook stoves. The same households were again provided with firewood to use on their old three stone open fire, over the same period of time. The firewood used was sourced locally from the

stores/vendors where the households normally got their firewood. The participants followed their normal cooking patterns and only used firewood from the provided pile for their cooking needs on a typical day throughout the KPT period. All the tests were conducted during a dry period in the Month of July 2023.

The carefully conducted KPT provided the best way to understand the impact of the energy efficient firewood cook stove (twin brick rocket stove) and the three stone open fire on fuel consumption. Because the KPT was conducted at the stove users' kitchen it provided information on the general household characteristics and behaviours (Bailis *et al.*, 2018). Adopting a paired sample study minimized the variability in social, economic and environmental factors that influence household fuel consumption. The table below summarizes the design adopted as per the objectives.

Table 3.1: Summary of the adopted design and data analysis per objective

Objective	Variable to be measured	Design	Data Analysis
1. To determine the usage rate of the energy efficient firewood cook stove (twin brick rocket) in relation to the other stoves used by the households in Siaya County.	The usage rate of the stoves adopted by the households	Descriptive – Quantitative and qualitative design	Descriptive - Quantitative Thematic Analysis
2. To evaluate sociocultural, economic and technological factors that influence	The sociocultural, economic and technological factors	Mixed Design - Descriptive (Quantitative and qualitative;	Descriptive – Quantitative Inferential Statistics

sustained usage of the energy efficient firewood cook stoves by households in Siaya County		Inferential statistics)	Thematic Analysis - Qualitative
3. To determine the relationship between sustained usage of the energy efficient firewood cook stoves and climate change mitigation.	Changes in CO ₂ e emissions (Δ CO ₂ e) and firewood consumption (Δ FC) due to the energy efficient cook stove's usage	Experimental	Quantitative Inferential statistics

Source: Researcher (2024).

3.3 The Target Population

To address the study objectives, the target population comprised rural households in Siaya County, already adopting the energy efficient firewood cook stove (twin brick rocket). The households were better placed to provide the necessary information given their hands-on experiences with the energy efficient stove (Willie, 2024). Also, representatives of the organizations promoting the energy efficient stoves as well as the relevant government agencies were targeted as the study's key informants.

3.4 Sampling Procedure and Sample Size Determination

Both purposive and simple random sampling methods were used to select the study participants. Initially, five out of the six Sub-Counties of Siaya, where the twin brick rocket energy efficient firewood cook stove had been disseminated, were purposively selected for the study. It was from the list of the households who had acquired the brick rocket energy efficient firewood cook stoves that the study participants were randomly sampled. A

sample size determination formula was used to help come up with appropriate sample size necessary for drawing a precise and accurate conclusion as described in section 3.4.1.

3.4.1 Household Questionnaire Respondents

Using a random number table in a simple random sampling method the household questionnaire respondents were selected (Singh & Masuku, 2014). The sampling frame was the list of the 127,242 household members who had acquired the twin brick rocket energy efficient firewood cook stove (Abbott & McKinney, 2013). Since the sampling frame was not homogeneous as participants were spread across the County, in Five Sub-Counties, care was taken to ensure that the sample size fairly represented the subgroups therein (Nassiuma, 2000). Therefore, Nassiuma (2000) formula was used to determine the sample size:

$$n = \frac{NC^2}{C^2 + (N-1)e^2}$$

Where:

n = sample size

N= accessible population

C= Coefficient of Variance

e= standard error

The formula gave 399 questionnaire respondents as shown below.

$$n = 127242 \times 0.4^2 / (0.4^2 + (127242-1) 0.02^2) = 398.75$$

Nassiuma (2000) recommends that ranges of $0.21 \leq C \leq 0.3$ for coefficient of variance and $0.02 \leq e \leq 0.05$ for standard error are suitable for most surveys. However, in this study a coefficient of variance equal to 0.4 and a standard error equal to 0.02 was used to make the sample size large enough but with the least error to ensure statistically valid results (Bailis *et al.*, 2018). A coefficient of variance equal to 0.3 with the least error margin of 0.02 would give a sample size of 225 from the target population of 127,242 households. A coefficient of variance equal to 0.4 with the least error margin of 0.02, on the other hand, gave a sample size of 399 which was large enough, manageable and cost-effective.

Moreover, the cumulative stove usage rate derived from the survey sample had to be statistically valid since it was to be used, together with the kitchen performance test (KPT) data, as a parameter for calculating the emission reduction by the energy efficient firewood cook stove. Bailis *et al.* (2018) notes that from past experiences with studies on household fuel consumption, the coefficient of variation is roughly 0.4, representing the highest variability expected in especially relatively large population.

The 399 questionnaire respondents sampled for the study were distributed across Siaya County as shown in Table 3.2.

Table 3.2: Sample distribution table for household survey

Sub-County	Household with the energy efficient stove	Sample size for household survey
Ugenya	17,596	55
Ugunja	17,423	55
Alego Usonga	33,140	104
Gem	51,407	161
Rarieda	7676	24
Total	127,242	399

Source: Researcher (2024).

3.4.2 Kitchen Performance Test (KPT) Participants

100 households were randomly sampled to participate in the experiment, to allow for derivation of a detailed data while keeping the KPT sample size manageable (Singh & Masuku, 2014). The determination of the sample size of the KPT participants followed Bailis *et al.* (2018) and Gold Standard (2011). According to Bailis *et al.* (2018), for a KPT adopting a paired-sample study, a sample size of at least 20 households is representative. Gold Standards (2021), on the other hand, recommends minimum sample size of 30 test subjects for a paired sample study.

However, Bailis *et al.* (2018) further states that statistically valid results can only be ensured with large enough samples. Similarly, Gold Standards (2021) argues that to take care of variations that may exist in the amounts of fuel used and saved, which is usually the case in KPTs, larger sample sizes may be considered. On the overall target population size, Gold Standard recommends that if target population is more than 1,000 households

then sample size of not less 100 households is applied (Standard G., 2021). In this study, given the sample frame of 127,242 households, 100 KPT participants were selected. The participants were proportionately distributed across the five Sub-Counties of Siaya County as shown in Table 3.3.

Table 3.3: Sample distribution table for KPT participants

Sub-County	Household with the energy efficient stove	Sample size for KPT
Ugenya	17,596	14
Ugunja	17,423	14
Alego Usonga	33,140	26
Gem	51,407	40
Rarieda	7676	6
Total	127,242	100

Source: Researcher, 2024

3.4.3 Key Informant Interviewees

Key informant interviewees were purposively picked from the respective organizations and government agencies promoting energy efficient cook stoves in Siaya County. Through the purposive sampling a judgmentally representative sample was achieved (Creswell & Poth, 2016). A list of staff of the various organizations including GIZ, Tembea, and Myclimate as well as Siaya County government departments responsible for energy and climate change, the people who had first-hand information about the topic, comprised the sample frames for the key informant interviewees.

3.5 Data Collection

The study utilized primary data in answering the research question and testing the stated hypotheses. The main instruments used in collecting data were a set of household questionnaires (Appendix II), Kitchen performance test (KPT) questionnaire (Appendix III) and key informant interview guide (Appendix IV).

3.5.1 The Use of Questionnaires

A set of questionnaires, with both closed and open-ended questions, was used to gather data from the households to address the objectives 1 and 2. Personal and specific details were obtained from the households using the closed-ended questions. The open-ended questions, on the other hand, were used when explanations and personal opinion was being sought. The use of questionnaires saved time and was affordable (Codó, 2008). With the questionnaires large amounts of confidential, valid and reliable information was collected from large number of respondents in a short period of time and in a relatively cost effective way (Kombo & Tromp, 2006). The questionnaires, which was in open data kit (ODK) format, was administered face-to-face to ensure that personal attention was given to the respondents and rapport built for high response rates. The researcher, in consultation with the assigned supervisors, reduced cases of non-response by keeping the questionnaire as short and simple as possible.

3.5.2 Semi-Structured Key Informant Interviews

Semi-structured interview schedule was used to collect information from the key informants. The data gathered from the key informants provided more qualitative information on the research objectives 1 and 2, in which the understanding of the usage

rate of the energy efficient firewood cook stoves by households and the factors influencing the sustained usage of the stoves in Siaya County were respectively sought. The interviews not only allowed the respondents to freely answer the questions but also gave opportunity for the researcher to probe the respondents further (Codó, 2008). The interviews, apart from being systematic, gave in-depth and reliable first-hand information and saved the researcher's time (Patton, 1990).

Interview method was regarded as a relatively superior research technique. For as long as rapport had been built and confidence assured certain confidential information that would otherwise have escaped the researcher was divulged. With interviews follow up on incorrect or incomplete answers were done and the respondents' sincerity gauged by the interviewer. Importantly, the researcher had the advantage of observing the respondents' actual behaviour and body language that proved useful for the qualitative analysis of the gathered data. Overall, asking each of the respondents a similar set of questions during the interview subjected them to the same stimuli (Schultze & Avital, 2011).

3.5.3 Data Collection in the Kitchen Performance Test

Both quantitative and qualitative data were collected during the KPT. Each participating household was visited at least four times on days 1, 3, 5 and 7. Based on the time of the day when the first visit was conducted, the subsequent visits happened in the households at almost the same time for each visit, but with a lot of care not to be intrusive. During the first visit, weights of the initial firewood supplied to the households were taken using calibrated weighing machine and recorded in a KPT questionnaire (Appendix III). In the subsequent visits, the quantity of fuel consumed were recorded by weighing the firewood

remaining in the provided pile. Firewood was added to the households' stock as was necessary to ensure that the households had adequate supplies for the entire KPT period. The procedure was repeated for the three stone open fire. The results were compiled and used in calculating the daily and annual firewood consumption by both the twin brick rocket energy efficient firewood cook stove and the three stone open fire.

According to Bailis *et al.* (2018), it is common practice to combine KPTs with household surveys in an effort to contextualize fuel consumption practices. Consequently, data was also captured on the household characteristics and other variables on the cooking habits over the KPT period including cooking duration, number of persons for whom the meals were prepared together with the qualitative aspects of stove performance.

3.5.4 Validity and Reliability of the Data Instruments

The degree to which a data instrument measures what it is supposed to measure is its validity (Kimberlin & Winterstein, 2008). Through a pre-test, the validity of the data collection instruments was checked in a pilot study. The pilot study served to test whether or not the respondents logically, clearly and easily understood the questions and if the stated responses were exhaustive; and the amount of time required to complete the questionnaire or the interview schedule. Through the pre-test the researcher was able to check if the collected variables could be processed and analyzed easily. The pilot study was carried out on a sample of five households adopting the energy efficient firewood cook stove in Ugunja Sub-County that had not been sampled to participate in the main study. During the pre-testing any questions interpreted differently by the respondents were rephrased in order to have the same meaning to all the respondents. The data tools were

improved before the actual data collection by incorporating the analyzed respondents' views, gathered during the pre-testing (Jagger, Duchelle, Dutt & Wyman, 2012).

Regarding reliability of the instruments, the researcher offered explanations as was necessary to ensure that the participants understood the questions and gave reliable answers. Besides, Cronbach's alpha (Cronbach, 1951) was used to measure the reliability of a set of survey items with yes and no questions (Santos, 1999). Cronbach's alpha was carried out in SPSS Statistics, version 29, using the Reliability Analysis (Statistics, 2013).

3.6 Data Analyses

The study data was analyzed both quantitatively and qualitatively (Bergin, 2018). Prior to commencing the data analyses, the researcher ensured that the questionnaire responses were complete, accurate and uniform and the data was well organized. Only fully filled-in questionnaires qualified for the analyses.

3.6.1 Quantitative Data Analyses

Quantitative analysis focused more on numbers and the data gathered through the use of questionnaires and experiments was chiefly analyzed quantitatively (De Leon, & Chough 2013). Using the Statistical Package for Social Sciences (SPSS) version 29 software, the data was analyzed both descriptively and by performing inferential statistics analysis. Descriptively the data was analyzed into percentages, frequency tables and charts, where applicable to present the findings, conclusions, and recommendations in a form that best told the story. The analyzed data presented in this manner added the visual aspect making it palatable to a wider audience. Significantly, the quantified data came in handy not only

in comparing and contrasting similar research findings but measuring change regarding the research topic.

Additionally, significance test was performed to establish the relationships between the dependent, independent and the control variables. The inferential analysis started by carrying out a normality test on the gathered data to decide on the tests to be performed. Since normal distribution was achieved, Pearson correlation-coefficient was used to measure correlation for the independent and dependent variables in the interval or ratio scale.

3.6.1.1 Measuring the Relationship between Sustained Stove Usage and Climate Change Mitigation

Using the data collected through the KPT, the energy efficient firewood cook stove's (twin brick rocket) climate change mitigation potential measured by the change in CO₂e emission (ΔCO_2e) was calculated based on changes in firewood consumption (ΔFC) and the climate-relevant emissions per unit of firewood the stoves helped save. Out of the 100 households that participated in the KPT, 100 households were found to be eligible for analysis, as shown in Table 3.4.

Table 3.4: Analyzed sample for the KPT

Sub-County	Sample size for KPT	Sample Analyzed
Ugenya	14	14
Ugunja	14	14
Alego Usonga	26	26
Gem	40	40
Rarieda	6	6
Total	100	100

Source: Researcher (2024).

The impact estimates was derived from comparison of firewood consumption by the energy efficient cook stove and the traditional three stone fire. Since the project fuel and baseline fuel were the same, the GHG emissions was calculated according to the below formula, adopted from the Gold Standard’s guidelines on Emission Reduction Calculations for Technologies and Practices to Displace Decentralized Thermal Energy Consumption (Standard G., 2011):

$$ER_y = \sum_{b,p} (N_{p,y} * U_{p,y} * P_{p,b,y} * NCV_{b,fuel} * (f''NRB_{b,y} * EF_{fuel,CO2} + EF_{fuel,nonCO2})) - \sum LE_{p,y} \quad (1)$$

Where:

ER_y - Emission reduction for total project cook stove activity in year y (tCO₂e/yr)

$\sum_{b,p}$ - Sum over all relevant (baseline b/project p) couples

N_{p,y} - Cumulative number of project technology-days included in the project database for project scenario p against baseline scenario b in year y

U_{p,y} - Cumulative usage rate for technologies in project scenario p in year y, based on cumulative adoption rate and drop off rate revealed by usage surveys (fraction)

$P_{p,b,y}$ - Specific fuel savings for an individual technology of project p against an individual technology of baseline b in year y, in tons/day, as derived from the statistical analysis of the data collected from the field tests

$f^{NRB}_{b,y}$ - Fraction of biomass used in year y for baseline scenario b that can be established as nonrenewable biomass

$NCV_{b,fuel}$ - Net calorific value of the fuel that is substituted or reduced (IPCC default for wood fuel, 0.015TJ/ton)

$EF_{b,fuel,CO_2}$ - CO₂ emission factor of the fuel that is substituted or reduced (112 tCO₂/TJ for wood)

$EF_{b,fuel,nonCO_2}$ - NonCO₂ emission factor of the fuel that is reduced

$LE_{p,y}$ - Leakage for project scenario p in year y (tCO₂e/yr)

3.6.1.1.1 Computation of the Parameters Used in the Equation 1

Parameters used in the model were computed or determined as described below.

i. Cumulative Stove Days ($N_{p,y}$)

From the stove users' database, 365 days was determined as the cumulative number of days the energy efficient firewood cook stove (twin brick rocket) was in use over the last one year.

ii. Cumulative Usage Rate ($U_{p,y}$)

The cumulative usage rate of the stoves was established from the analysis of the household survey data.

iii. CO₂ Emission Factor of the fuel ($EF_{b,fuel,CO_2}$)

The CO₂ emission factor of the firewood was calculated as shown in Table 3.5.

Table 3.5: Calculated CO₂ emission factor of firewood (EF_{wood}).

Item	Unit	Value	Source
EF wood	(tCO ₂ e/TJ)	112	IPCC default 2006 (Table 2.5)
NCV wood	(TJ/t fuel)	0.0156	IPCC default 2006 (Table 1.2)
EF wood	(tCO ₂ e/t fuel)	EF wood * NCV wood 112 * 0.0156 = 1.7472	Calculated

Source: Researcher (2024).

iv. NonCO₂ Emission Factor of the fuel (EF_{b,fuel,nonCO2})

The nonCO₂ emission factor of the firewood was calculated by first computing the emission factors of Methane and Nitrous Oxide based on the IPCC 2006 default values then summing the emission factor values as shown in Table 4.12.

Table 3.6: Calculated NonCO₂ Emission Factor of the fuel

Item	CH ₄ Value	N ₂ O Value	Source
EF _{wood} (tCO ₂ e/TJ)	0.3	0.004	IPCC default 2006
GWP	28	265	Default
NCV _{wood} (TJ/t fuel)	0.0156	0.0156	IPCC default 2006
EF _{wood} tCO ₂ e/t fuel	EF _{wood} (NH ₄) = EF _{wood} * GWP(CH ₄) * NCV _{wood} = 0.3*28*0.0156	EF _{wood} (N ₂ O) = EF _{wood} * GWP (N ₂ O)* NCV _{wood} 0.004*265*0.0156	Calculated

$$\begin{aligned}
 &= 0.1310 & &= 0.0165 \\
 \text{EF}_{\text{NonCO}_2} & \text{EF NonCO}_2 = \text{EF wood (NH}_4\text{)} + \text{EF wood (N}_2\text{O)} & \text{Calculated} \\
 &= 0.1310 + 0.0165 \\
 &= 0.1475
 \end{aligned}$$

Source: Researcher (2024).

v. Non-Renewable Biomass Fraction ($f^{\text{NRB},b,y}$)

A 92% default value for Kenya by CDM was adopted as the fraction of biomass used by the three stone open fire that could be established as nonrenewable biomass.

vi. Net Calorific Value of the fuel ($\text{NCV}_{b,\text{fuel}}$)

Whereas IPCC 2006 gives NCV default for wood fuel, being 0.0156TJ/ton, the parameter was not directly substituted in the equation. The parameter was instead used to calculate the EF, expressed in units of tonnes of carbon dioxide per unit tonne of fuel ($\text{tCO}_2/\text{t}_{\text{fuel}}$), making the NCV no longer applicable in the equation used (Standards G., 2011).

vii. $\text{LE}_{p,y}$

From the Tembea's energy efficient cook stove for Siaya Communities project design document, leakage for project scenario was 0 $\text{tCO}_2\text{e/yr}$ (Tembea, 2017).

The parameter values used in the model, whether calculated from the KPT data or default IPCC/CDM values, were as summarized in Table 3.7.

Table 3.7: Parameters used to quantify the CO₂e emissions

Item	Unit	Value	Source
Days stove in use (N)	days	365	Stove users' database
Cumulative Usage Rate (U)	fraction	0.710	Calculated from household survey data
Fuel Savings (P)	tfirewood/day/stove	0.0031	calculated from KPT data
Non-renewable biomass fraction (NRBf)	fraction	0.92	CDM default value for Kenya
Net Carolific Value for wood (NCV wood)	(TJ/ton fuel)	0.0156	IPCC default 2006
CO ₂ emission factor for wood (EF wood, CO ₂)	tCO ₂ e/t wood	1.7472	Calculated from KPT data
Non-CO ₂ emission factor for wood (EF wood, nonCO ₂)	tCO ₂ e/t wood	0.1476	Calculated from KPT data
Leakage LE	tCO ₂ e/year	0	Project Design Document
Daily Firewood Consumption by Three stone open fire	t/day/stove	0.0075	Calculated from KPT data
Daily Firewood Consumption by Twin brick rocket stove	t/day/stove	0.0044	Calculated from KPT data

Source: Researcher (2024) and IPCC (2006).

3.6.2 Qualitative Data Analysis

The qualitative analysis was conducted to help the researcher tell the story explicitly. Thematic analysis was conducted on the qualitative data in line with the research objectives and conceptual framework. Qualitative data from the interviews and the questionnaire's open-ended questions were subjected to a coding scheme. All the coded data were examined by the researcher to make critical inferences. By reading many times while making notes, drawing diagrams and brainstorming, the researcher familiarized with the text. Hence the researcher knew well the data to easily locate information that supported

the interpretation. Only responses that align with a theme that addressed the research question or hypotheses were considered as useful information (Creswell & Poth, 2016). Noteworthy, given the constant interplay between data collection and analysis involved in qualitative research, the analysis more or less started immediately the data collection began to help the researcher determine any notable patterns in the responses to be able to facilitate the subsequent data collection ((Bergin, 2018).

3.7 Ethical Considerations

This study ensured confidentiality and anonymity by the respondents being only identified by codes and/or pseudo-names and no detail was stored in a form that would lead to their identification (Kombo & Tromp, 2006). The information obtained from the respondents was held in confidence. The participants' consent was sought before any information was recorded from them. The respondents were informed of what to expect from their participation in the study and only those who volunteered participated (Fisher & Anushko, 2008). The researcher got approval from Masinde Muliro University of Science and Technology's department of postgraduate studies (MMUST-DPS) and obtained a research permit from the national commission for science, technology and innovation (NACOSTI). The researcher took responsibility for the study and its outcome.

3.8 Limitations of the Study

The study heavily relied on survey data from the households to determine the stoves' usage rate and evaluate the factors that influence sustained usage. Whereas the survey data provided valuable insights to the study, by bringing out the specific aspects of the stoves usage and household dynamics, surveys are subject to bias. Research has shown that

individuals often rely on their memory and are likely to respond as they think they should and may over-rate themselves on desirable traits while under-rating themselves on undesirable traits, potentially leading the researcher to wrong conclusions making it hard to generalize the findings to other contexts (Coughlan, Cronin & Ryan, 2009). To mitigate this limitation, data was collected face to face so the researcher had the advantage of observing the respondents' actual behaviour and body language as well as stove usage indicators such as fresh ash, burned wood, among others in the stove to gather useful qualitative data to corroborate the quantitative findings. Besides, the researcher subjected all the respondents to the same stimuli by asking similar set of questions to each. Significantly, the data collection instruments were kept as short and simple as possible and personal attention given to respondents during the actual data collection.

Another limitation could be due to the changes in weather conditions at the time the KPT was carried out. The KPT was conducted end of July and at the beginning of August 2023 when the study area was receiving significant amount of rainfall. However, the rainfall episodes were unevenly distributed with dry spells in between (Kenya Meteorological department, 2023). Particularly, there was a dry spell during the week the KPT for the energy efficient cook stove was being done. The week when KPT for the TSOF happened there was rainfall. The experienced changes in weather conditions could potentially affect firewood consumption (Bailis *et al.*, 2018). The recorded fuel consumption could probably have been highest for the TSOF but lowest for the energy efficient firewood cook stove. It is likely to use more firewood during rainy seasons compared to dry spells. Nonetheless, the study finding that the percentage for firewood savings by the energy efficient firewood cook stove (twin brick rocket) is 41.3% is dependable as it is closer to 40% reported by

GIZ (2018), Orlale and Odee (2013) and TaTEDO (2005) cited in Njogu (2011). Notably, the rate is far below 60% reported by Kamfor (2002) for similar stoves. Also, Bailis *et al.* (2018) observes that many programs have reported reductions in fuel consumption of 50% or more against their recommendation of 30% savings.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 The Study Response Rate

The study achieved 100% response for both the household survey and KPT as summarized in Table 4.1.

Table 4.1: The study response rate

Respondent Category	Target Sample Size	Achieved Sample	Response Rate
Household Survey	399	399	100%
KPT	100	100	100%
Key Informant Interviewees	10	8	80%

Source: Researcher (2024).

4.2 Characteristics of the Survey Respondents

The characteristics of the respondents in terms of gender, age, education level, household size and household income were descriptively analyzed and presented as in the following section.

4.2.1 Gender of the respondents

Gender distribution of the respondents were as shown in Figure 4.1.

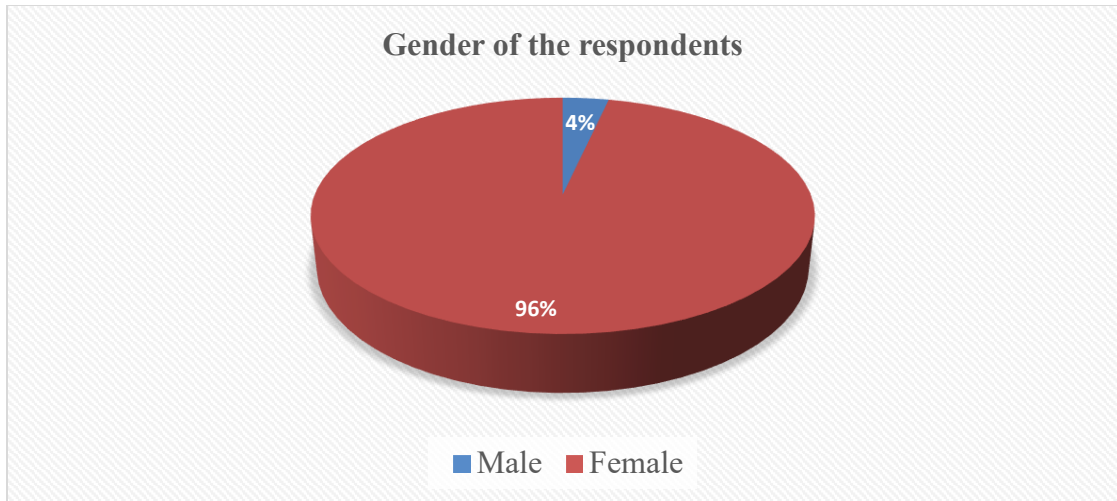


Figure 4.1: Gender of the respondents

Source: Researcher (2024).

As in Figure 4.1, of the 399 respondents 14 (4%) were male and 385 (96%) were female. There were more female respondents than the male ones. In the study area cooking activity has been culturally assigned to women making them the primary users of the cooking technologies. This could probably explain why there was gender disparity in favour of women among the randomly sampled respondents.

4.2.2 Age of the respondents

The age brackets of the respondents were as shown in Figure 4.2.

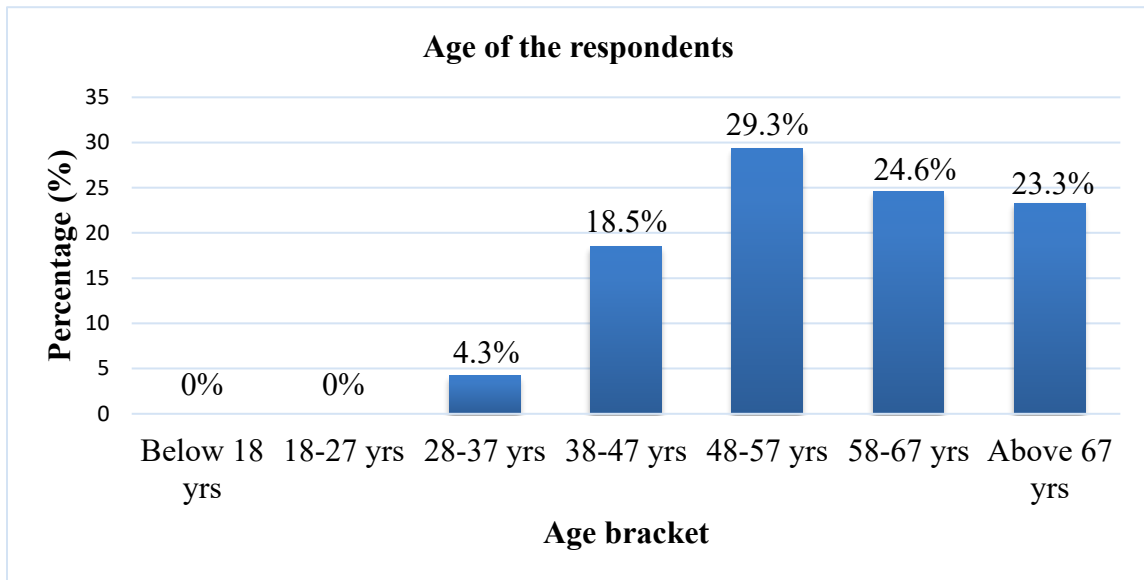


Figure 4.2: Age of the respondents

Source: Researcher (2024).

As in the Figure 4.2, no respondent was aged below 28 years. 17 (4.3%) were aged 28 to 37 years, 74 (18.5%) aged 38 to 47 years, 117 (29.3%) aged 48 to 57 years, 98 (24.6%) aged 58 to 67 years and 93 (23.3%) aged above 67 years. Probably there is an age limit below which one may not own an energy efficient cook stove in the area.

4.2.3 Education level

The respondents' education level was as presented in Figure 4.3.

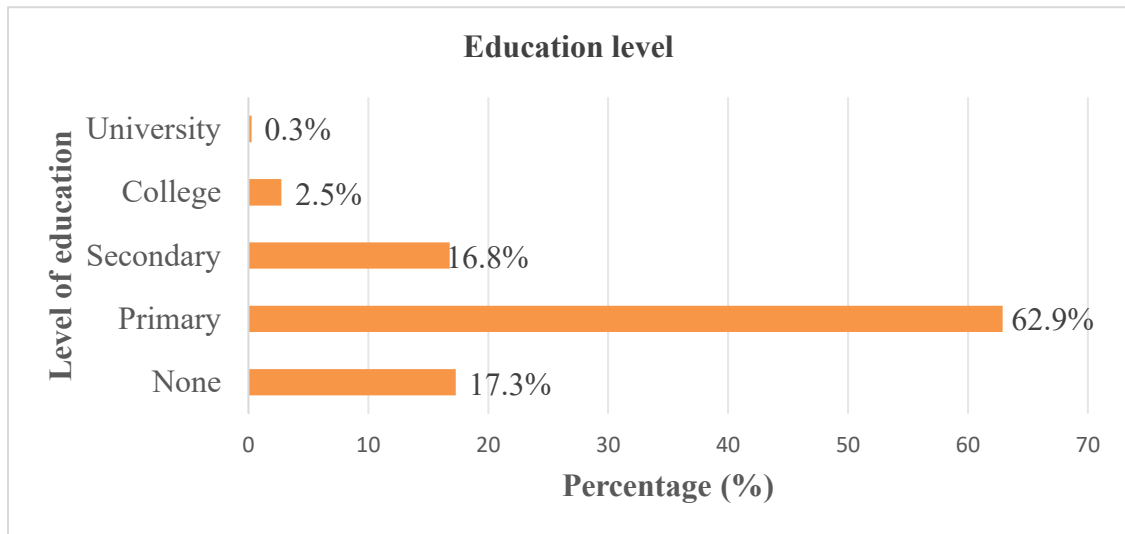


Figure 4.3: Education level of the respondents

Source: Researcher (2024).

Figure 4.3 demonstrates that 251 (62.9%) of the survey respondents had attained primary school level education while 67 (16.8%) had secondary level education. Whereas only 12 (3.1%) had post-secondary school level education (College - 2.8% and University - 0.3%), 69 (17.3%) had no formal education.

4.2.4 The household size of the respondents

The average household size was determined as in Table 4.2

Table 4.2: Average household size

Number of households surveyed	Total number of people living in the 399 households	Average household size
399	2072	5.2

Source: Researcher (2024).

As shown in Table 4.1, the average household size was about 5 members. This is slightly above the average household size of 4 members reported for the County by KNBS (2019) population census.

4.2.5 Household income of the respondents

The monthly income of the households was as in Figure 4.4.

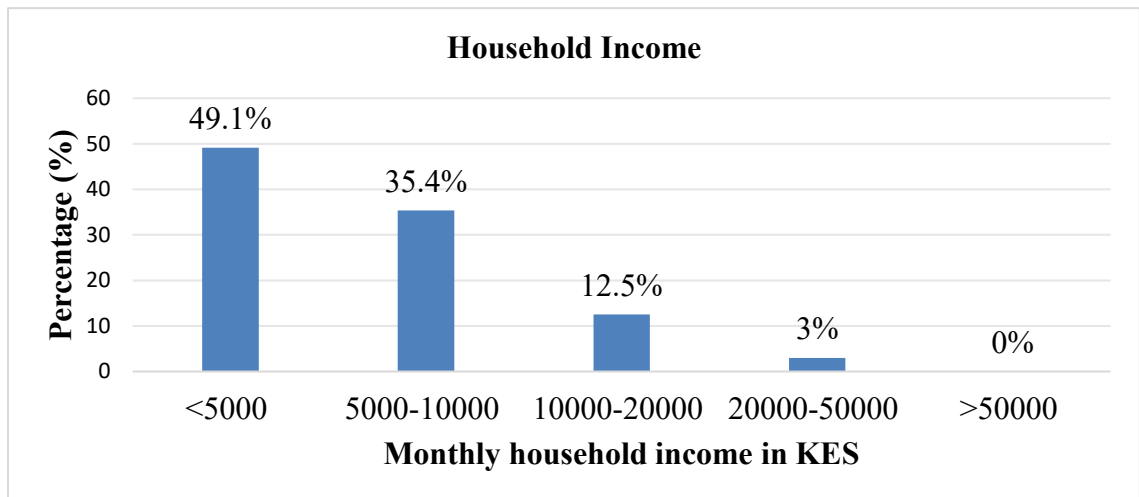


Figure 4.4: Household income of the respondents

Source: Researcher (2024).

In Figure 4.4, 196 household (49.1%) had monthly income less than Kenya shillings (KES) 5000. For 141 (35.3%) the monthly income ranged between 5000 to 10,000. 50 (12.5%) had between KES 10,000 and 20000 monthly incomes. 12 (3.0%) had monthly income of KES 20000 to 50000. No household had monthly income greater than KES 50,000. The interpretation is that about 70% of the households were poor, living below the international poverty line of \$2.15 per day for each household member (Cowling, 2024).

4.3 The Usage Rate of the Firewood Cook Stoves

The first objective of the study sought to determine the usage rate of the energy efficient firewood cook stove in relation to the other stoves used by the households in Siaya County. To better understand the usage rate, the proportion of households using the energy efficient firewood cook stove (twin brick rocket) throughout the stove's lifespan was established. Also, usage rates of the old three stone open fire as well as the other cooking devices by the households were analyzed. Data was collected through a survey conducted in 399 households which had adopted the twin brick rocket energy efficient firewood cook stove. The findings were as presented and discussed in the subsequent sections.

4.3.1 The Usage Rate of the Energy Efficient Firewood Cook Stove

The respondents were asked to state whether the installed energy efficient firewood cook stove (twin brick rocket) was being used, no longer used or had never been used. Interviewer observation (checking for indicators such as fresh ash, burned wood, among others in the stove) was also done to corroborate the household responses presented in the Table 4.3.

Table 4.3: The energy efficient firewood cook stove (twin brick rocket) usage rate

Usage status	Stove users' response		Interviewer's observation	
	Frequency (f)	Percentage (%)	Frequency (f)	Percentage (%)
Stove has never been used	1	0.3	1	0.3
Stove is no longer used	5	1.3	5	1.3
Stove is used	393	98.4	393	98.4
N	399	100.0	399	100.0

Source: Researcher (2024).

Table 4.3 indicates that greatest percentage of the installed energy efficient firewood cook stoves (twin brick rocket) were being used. 393 (98.4%) of the installed energy efficient firewood cook stoves were being used. Only 6 (1.6%) of the energy efficient firewood cook stoves had never been or were no longer used.

The study further investigated the reasons for the high usage rate reported by the households, and the finding was as presented in Figure 4.5.

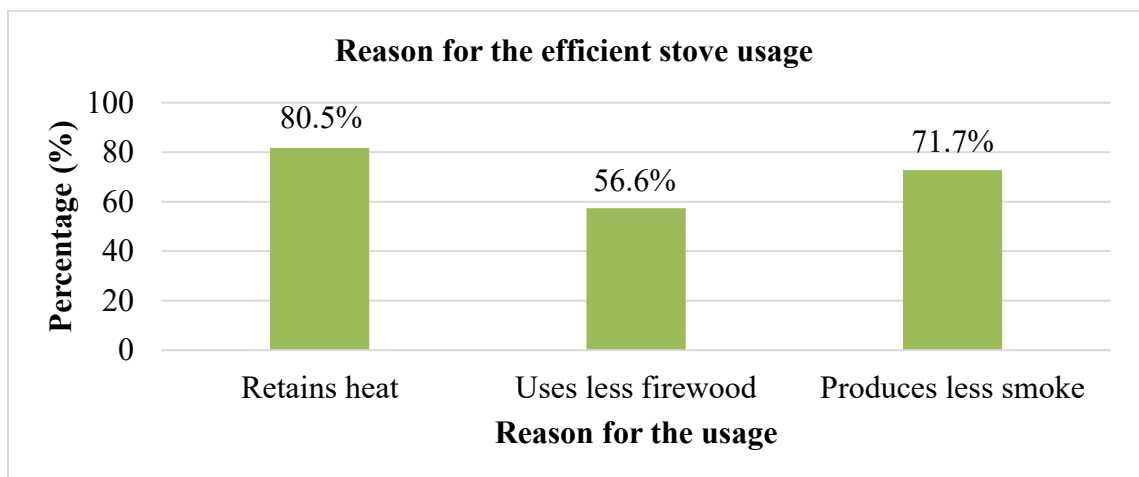


Figure 4.5: Reasons for using the twin brick rocket stove

Source: Researcher (2024).

Figure 4.5, indicates that the energy efficient stove was being used because for 321 (80.5%) it retains heat, to 286 (71.7%) it produces less smoke and to 226 (56.6%) it consumes less firewood. In support of this finding one of the key informant interviewees also remarked that *“a stove’s contribution towards the conservation of firewood and enhancement of a clean cooking environment, free from excess smoke, is an important factor for the Siaya households. The households prefer stoves with ability to retain heat thereby providing them with additional opportunity to simmer or keep their food warm for long or even warm water for bathing without having to use additional firewood”*.

The households used the stove for multiple reasons but its heat retention capacity was an important factor for the greatest percentage of the users (80.5%). Perhaps, by retaining heat the stove helped the households accomplish their cooking needs with less firewood. The heat retention capacity kind of solved the problem of firewood consumption leading to the relatively low score of 56.6% for the stove ‘uses less firewood’ by the households. Remarkably, health concern seemed to be another important factor for the households. Less smoke emission by the energy efficient cook stove motivated some 71.7% of the households to use the stove. Less smoke was associated with less health problems by the households.

The findings agree with previous studies (Ochieng, Vardoulakis & Tonne, 2013; Kamfor, 2002) that due to their higher combustion efficiency rocket stove remains one of the most effective stove designs used in developing countries, known to use less fuel and produce less smoke compared to three stone open fire. Rehfuess *et al.* (2014) and Shen *et al.* (2014) also established that stoves whose design addresses fuel saving needs are highly used by households. Also, studies by Bensch *et al.* (2021) and Hudelson *et al.* (2002) reported that

households prefer to use energy efficient firewood cook stoves because of their higher combustion efficiency.

4.3.1.1 The Frequency of the Energy Efficient Firewood Cook Stove Usage

Beyond the generally high usage rate depicted in Table 4.2, the study determined the energy efficient firewood cook stove's (twin brick rocket) daily usage frequency by comparing the households' normal daily cooking pattern with the average number of times the energy efficient firewood cook stove was used for the cooking. The information was useful for evaluating the energy efficient firewood cook stove's usage rate in relation to the other cooking devices in the households. The result generated was as shown in Figure 4.6.

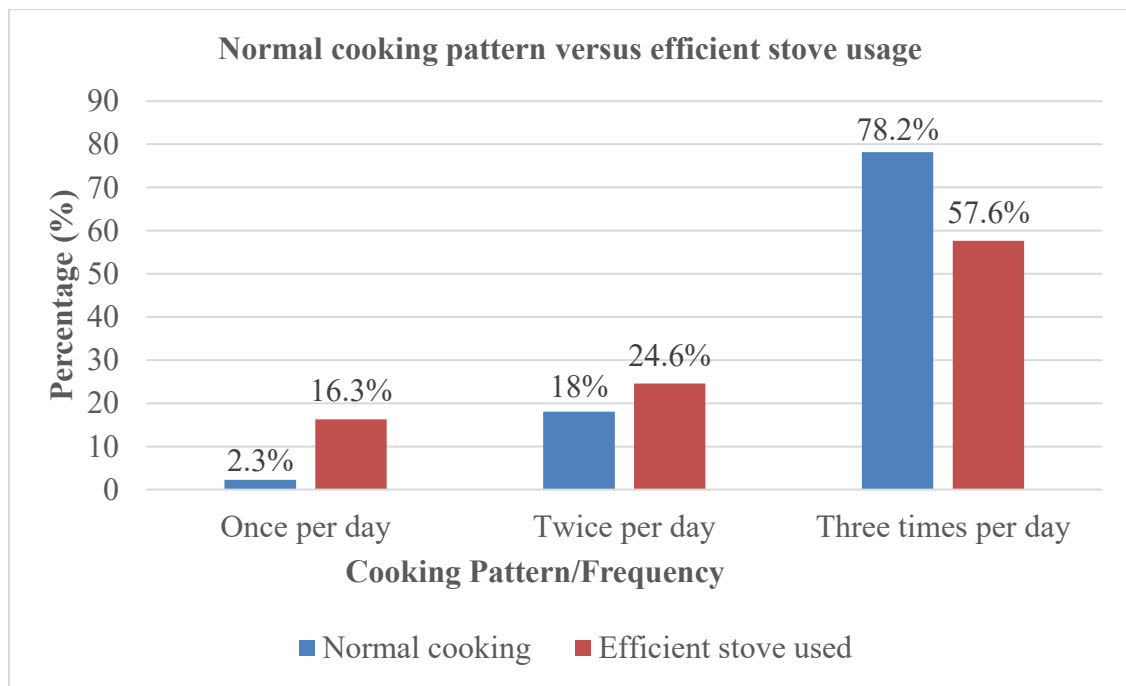


Figure 4.6: Normal cooking pattern compared with the energy efficient stove usage frequency

Source: Researcher (2024).

Figure 4.6 shows inconsistency in the use of the energy efficient firewood cook stove (twin brick rocket) relative to the households' normal daily cooking pattern. 312 (78.2%) households had a normal cooking pattern of three times per day yet only 230 (57.6%) cooked on the energy efficient cook stove three times per day. This indicates that 82 (20.6%) of the households who normally cooked three times every day did not use the energy efficient firewood cook stove every time they were cooking.

Notably, the energy efficient firewood cook stoves were used once or twice per day more than the households' normal cooking pattern of once or twice per day. 65 (16.3%) of the households using the energy efficient firewood cook stove once per day was far more than 9 (2.3%) of the households whose normal cooking pattern was once per day indicating that 56 (14%) of the households cooked once per day on the energy efficient stove more than they did with the other cooking devices. Similarly, 98 (24.6%) households cooking on the energy efficient stove twice per day were more than the 72 (18%) whose normal cooking pattern was twice per day, implying that some 26 (6.6%) of the households cooked twice per day on the energy efficient stove more than they did with the other cooking devices.

The implication of this result was that the households were not entirely using the energy efficient firewood cook stoves (twin brick rocket) for their cooking. The result concurs with Gill-Wiehl *et al.* (2023) that households inconsistently use the adopted energy efficient cook stoves. Gill-Wiehl *et al.* (2023) reported a 48% sustained usage rate of energy efficient cook stoves registered as carbon offset cook stoves under the Gold Standard (GS) and Verified Carbon Standard (VCS).

The study further examined the frequency of the energy efficient cook stove usage across the stove ages as shown in Figure 4.7.

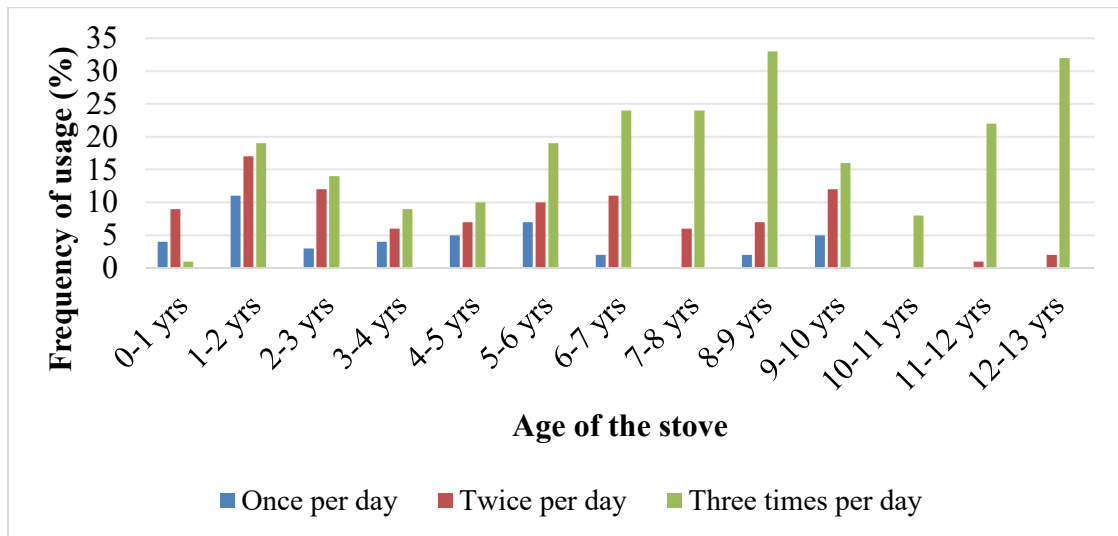


Figure 4.7: Stove usage frequency across the stove ages

Source: Researcher (2024)

Figure 4.7 points out that usage frequency of the energy efficient firewood cook stove (twin brick rocket) declined over the first year of installation (being used once or twice more than was used three times per day) before beginning to stabilize at the second year. This result depicts a time lag between the energy efficient stove installation and steady usage.

Particularly, the households took about one year to fully switch to the new cooking device (twin brick rocket) and the stove daily usage frequency increased over time. In the respective age categories, the energy efficient stoves aged 2 years and above were mostly used three times every day. None of the stoves aged between 10 and 13 years was used once per day. Perhaps, it takes the households adopting a new cook stove quite some time to learn how to effectively use the new stove while they also slowly start to see and enjoy its benefits.

A study by Pillarisetti, *et al.* (2014) in Haryana, India, that used a stove usage monitoring system (SUMS) on an energy efficient biomass stove (Philips HD4012 fan-assisted stove) also reported a steady decline in the energy efficient stove usage before stabilizing after approximately 200 days of use. Similarly, Brant *et al.* (2013) monitored an energy efficient cook stove (*Jiko Poa* - rocket-type biomass cook stove) usage in Kenya and reported gradual decrease in the stove's usage per day between the first week and the fifth week. Brant *et al.* (2013) attributed the initially declining usage frequency to the known limitations of the rocket stove technology including the impossibility of leaving the stove unattended when preparing slow cooking foods or when the stove users were not able to give the required attention.

Another important revelation (new knowledge) from Figure 4.7 is that, as opposed to previous reports that a consistently used brick rocket stove has a lifespan of 5-7 years (GIZ, 2018), the surveyed households still used their twin brick rocket cook stoves which were already 13 years old. With proper maintenance the stoves could serve the users for longer periods spanning over 13 years.

4.3.1.2 Reasons for the Energy Efficient Firewood Cook Stove's Inconsistent Usage

The study also explored why the energy efficient firewood cook stove (twin brick rocket) was not being used consistently. The survey respondents were asked to state the reasons for not using the energy efficient firewood cook stove every time they cooked and the finding was as in the Figure 4.8.

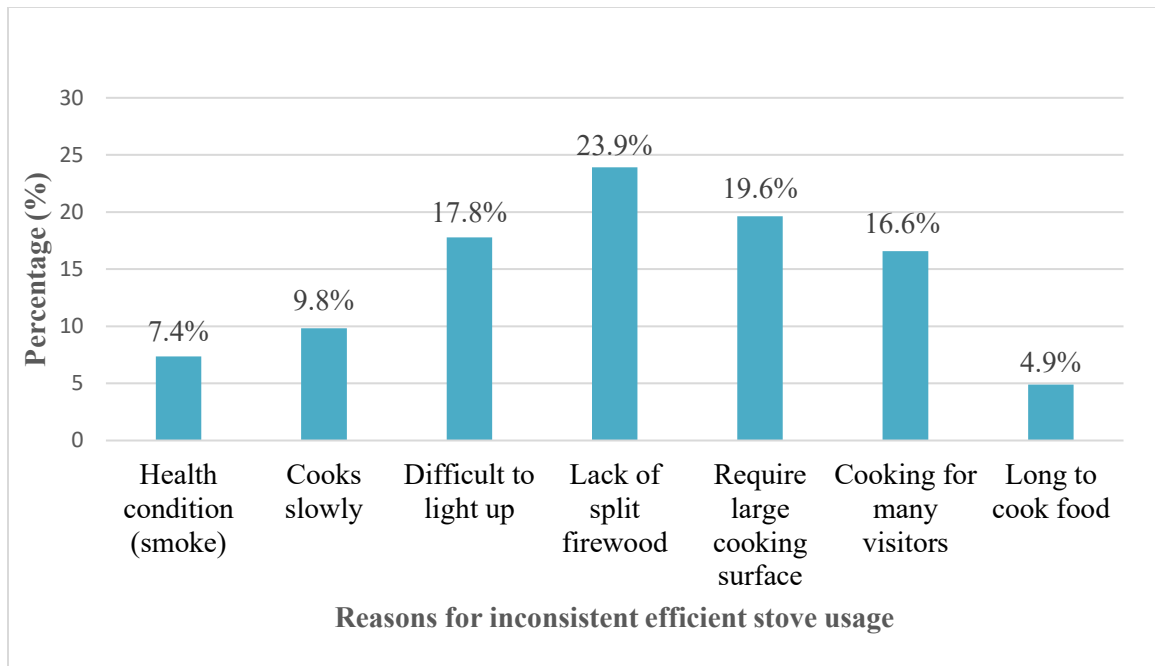


Figure 4.8: Reasons for not consistently using the twin brick rocket cook stove

Source: Researcher (2024).

From Figure 4.8, 39 (23.9%) of the energy efficient firewood cook stoves (twin brick rocket) were not consistently being used due to lack of split firewood. Respectively, 32 (19.6%) and 29 (17.8%) households did not consistently use the efficient stove when they required a large cooking surface and because the efficient was difficult to light up. Another 27 (16.6%) did not use the stove when cooking for many visitors. 16 (9.8%) also felt that the energy efficient firewood cook stove cooked slowly and would only use it when there was no time constraint. While 12 (3%) did not consistently use the stove when preparing long to cook food, 8 (2%) avoided the stove’s consistent use to reduce exposure to smoke.

The reasons for inconsistent usage of the energy efficient firewood cook stove were mainly technological and sociocultural issues. The leading reasons for the inconsistent usage were technological in nature, including lack of split firewood with which the users felt the stove

worked best, need for a large cooking surface and difficulty to light up the stove especially by children, making it a preferred option for use by mainly adults. Moreover, the stove was considered to be cooking slowly by some households and would only use it when there was no time constraint. This could have also contributed to the finding that some households did not use the efficient stove when preparing long to cook meals. The sociocultural issues that made the households not to use the stove were when when cooking for many visitors and to reduce exposure to smoke, most probably due to health condition. This result reaffirms the studies by Prah *et al.* (2021), Bensch *et al.* (2021), Hoigt (2019), Sundararaman *et al.* (2016) and Ruiz-Mercado *et al.* (2011) that the sustained usage of improved cook stoves by households is expected to take place in a dynamic system with strong interactions between the stove technology (design, efficiency, fuel sources/availability) and the wider socioeconomic contexts. That the energy efficient firewood cook stove's generally high usage rate due to its ability to retain heat, consume less firewood or produce less smoke shown in section 4.3.1 did not translate into consistent usage as shown in section 4.3.1.1 is a clear manifestation of the complexity of the interactions.

4.3.2 The Usage of Three Stone Open Fire (TSOF)

Given that some 20.6% of the adopted energy efficient stoves were not consistently being used, it was imperative for the study to investigate if the three stone open fire was still being used in the households, and if so, to what extent. When asked if the old TSOF was still available and whether in use or not in the households, the finding was as shown in Figure 4.8.

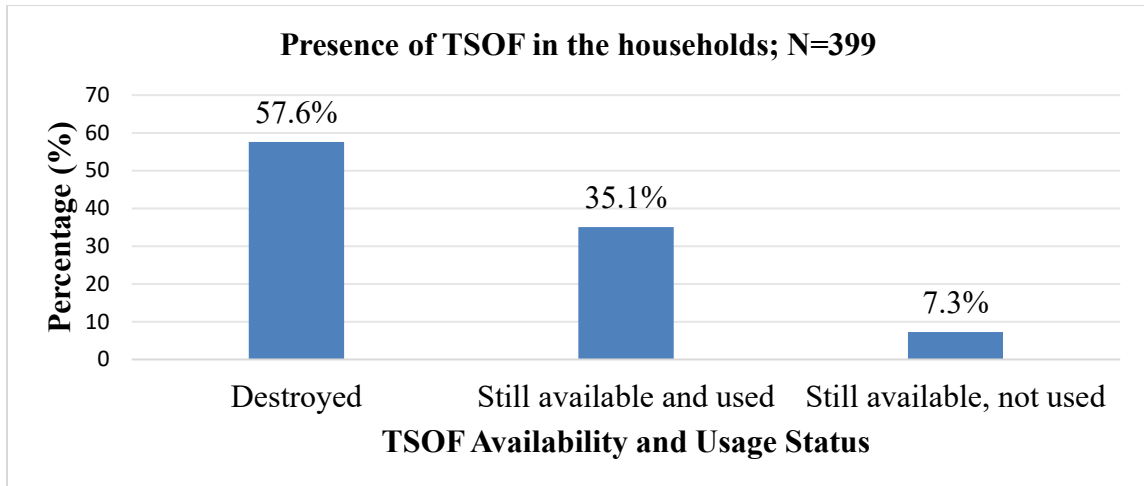


Figure 4.9: Old three stone open fire presence in the households

Source: Researcher (2024)

Figure 4.9 indicates that TSOF was still present and in use in the households even after installing the energy efficient cook stove. Although 230 (57.6%) TSOF had been destroyed, 169 (42.4%) of the households still kept their old cook stoves with 140 (35.1%) still in use.

The study further examined how persistently the three stone open fire was still being used in the households. The most immediate time considered was the past two weeks. When the households were asked if they ever used the TSOF in the past two weeks and if so, how frequently, the findings were as in Table 4.4.

Table 4.4: Old three stone open fire usage in the past two weeks

TSOF usage in the past two weeks	Frequency	Percent (%)
never	267	66.9
once per day	63	15.8
twice per day	16	4
three times per day	9	2.3
once every two days	10	2.5
once per week	27	6.8
twice per week	7	1.8
N	399	100.0

Source: Researcher (2024)

Table 4.4 demonstrates that in the past two weeks the three stone open fire had been used in 132 (33.1%) households. 63 (15.8%), 16 (4%) and 9 (2.3%) of the TSOF had been respectively used once, twice and three times every day. Some 11.1% of the households also used their old three stone open fire at once every week.

A substantial number of the households still used the TSOF even after acquiring the energy efficient stove with 88 (22.1%) having been used every day. This finding contradicts the energy ladder theory (Osiolo, 2021; Ruiz, 2012) holding that households will entirely replace their traditional cooking devices with energy efficient alternatives as soon as they overcome their access constraints. There seems to be factors beyond the physical access to energy efficient firewood cook stoves that determine whether households will entirely use them or fall back to their old stoves.

4.3.2.1 Reasons for Using the Old Three Stone Open Fire

The reason why the TSOF was still being used were explored. When the respondents were asked why they had used the traditional three stone open fire, especially in the past two weeks, the responses were as presented in Figure 4.10.

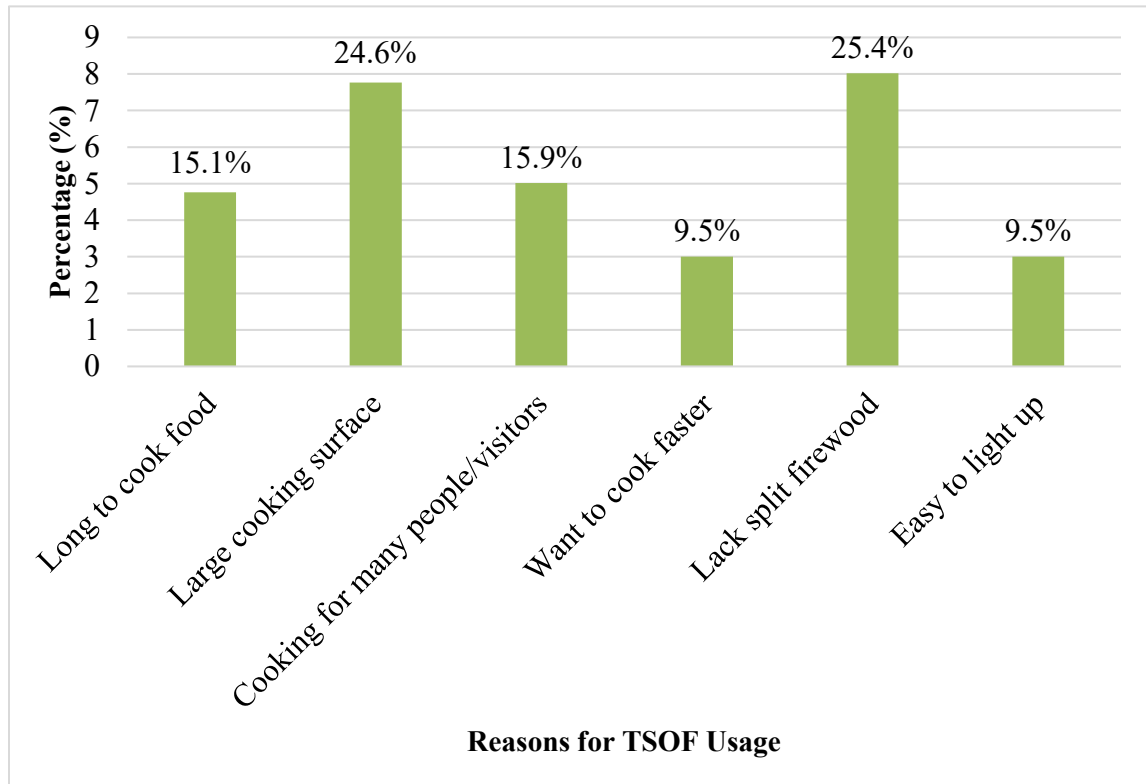


Figure 4.10: Reasons for using the three stone open fire

Source: Researcher (2024).

Figure 4.10 demonstrates that of the 132 households who had used their old stoves in the past two weeks, 34 (25.4%) used the stove because they lacked split firewood. 33 (24.6%) used the TSOF because it allowed for enlarging the cooking surface to use a large cooking pot. 21 (15.9%) used the TSOF when preparing meals for many people or visitors. 20 (15.1%) felt that the TSOF was more suitable for foods that took long to cook. Households

that used the TSOF because they felt it cooked faster and was easy to light up each stood at 12 (9.5%).

As was the case with inconsistent use of the energy efficient cook stove in section 4.3.1.2, the leading reason for which the households used the TSOF was lack of split firewood followed by the need for a large cooking surface. Most likely, the households found it more convenient to use the readily available biomass fuels like small twigs on the three stone open fire than on the energy efficient cook stove. This finding concurred with an observation by one of the key informant interviewees that *“fuel options readily available to the households could influence which stove to use based on the perceived suitability of the fuel to the stove being used”*.

That the TSOF could be easily enlarged to accommodate large cooking pots, perceived to be cooking faster as well as being easier to light up than the energy efficient cook stove also significantly contributed to its usage. Hooper *et al.* (2018) related the pervasive use the traditional three stone open fire among women in rural Senegal to its ability to provide large cooking capacity and rapid-intense heat generation that better satisfied the practical needs of the surveyed cooks than the alternative stove options.

Generally, the reasons for which the households used their old stove were mainly technological issues touching on stove design, efficiency and fuel availability as well as sociocultural ones including the number of people to be cooked for and the type of food to be cooked. Other studies had linked socio-cultural (Njau & Matto, 2024; Muwanga *et al.*, 2023; Akintan *et al.*, 2018) and technological (Hooper *et al.*, 2018) issues to persistent use of the three stone open fire.

4.3.3 Other Cooking Devices' Usage

The study went further to determine if the households had any other cooking devices and the usage rate of such devices where they existed. The result was as shown in Table 4.5.

Table 4.5: Households with other cooking devices

Other cooking devices	Frequency	Percent (%)
No	313	78.4
Yes	86	21.6
N	399	100.0

Source: Household survey data (2024)

From Table 4.5, 86 (21.6%) of the households had other cooking devices besides the energy efficient firewood cook stove (twin brick rocket) and/or the old three stone open fire. This result demonstrates that other cooking devices were present in the households. The households with other cooking devices confirmed that they occasionally used the devices.

Specifically, the other cooking devices used in the households were as presented in the Figure 4.11.

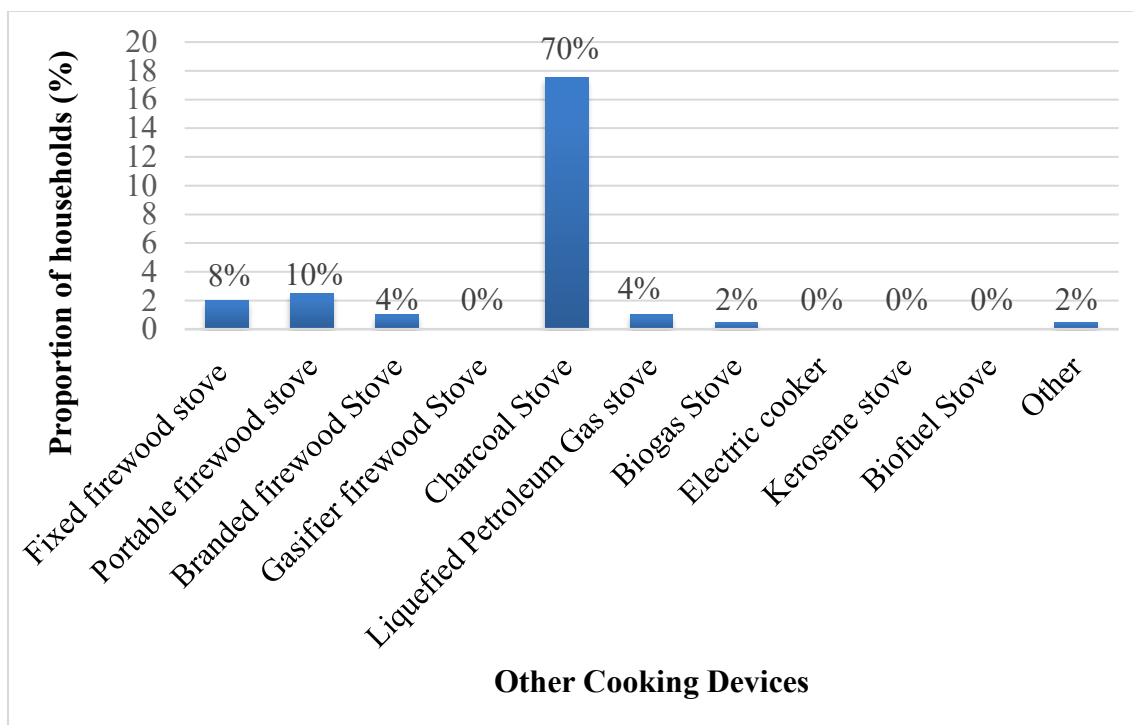


Figure 4.11: The other cooking devices used in the households

Source: Researcher (2024).

Figure 4.11 indicates that of the 86 households with other cooking devices, 60 (70%) used charcoal stove as their other cooking device. 7 (8%), 9 (10%) and 3 (4%) households also had other firewood cook stoves including fixed, portable and branded firewood stoves respectively. Another 3 (4%) and 2 (2%) households were using LPG and Biogas stoves respectively. None of the households used gasifiers, electric cooker, kerosene and biofuel stoves.

While other firewood and gas cook stoves were simultaneously being used (stacked) in the households, charcoal stove is seen to be the other most popular cook stove. This implies that in spite of 99% of the surveyed household relying on firewood as their main source of fuel (Researcher, 2024), charcoal remains an important fuel for the Siaya households.

Significantly, the households seemed to have stopped using kerosene stoves and electric cooker as earlier reported by the Siaya County Government (SCG, 2018) that the County’s cooking devices included kerosene stove (0.6%) and electric cooker (0.07%). Perhaps the low household income levels put access to electricity and kerosene for cooking out of the households’ reach or the households stopped using the kerosene because of the associated pollution resulting from GHGs emissions.

4.3.3.2 The Other Cooking Devices Usage Frequency

Figure 4.12 presents the frequency with which each of the other cooking devices were used by the households.

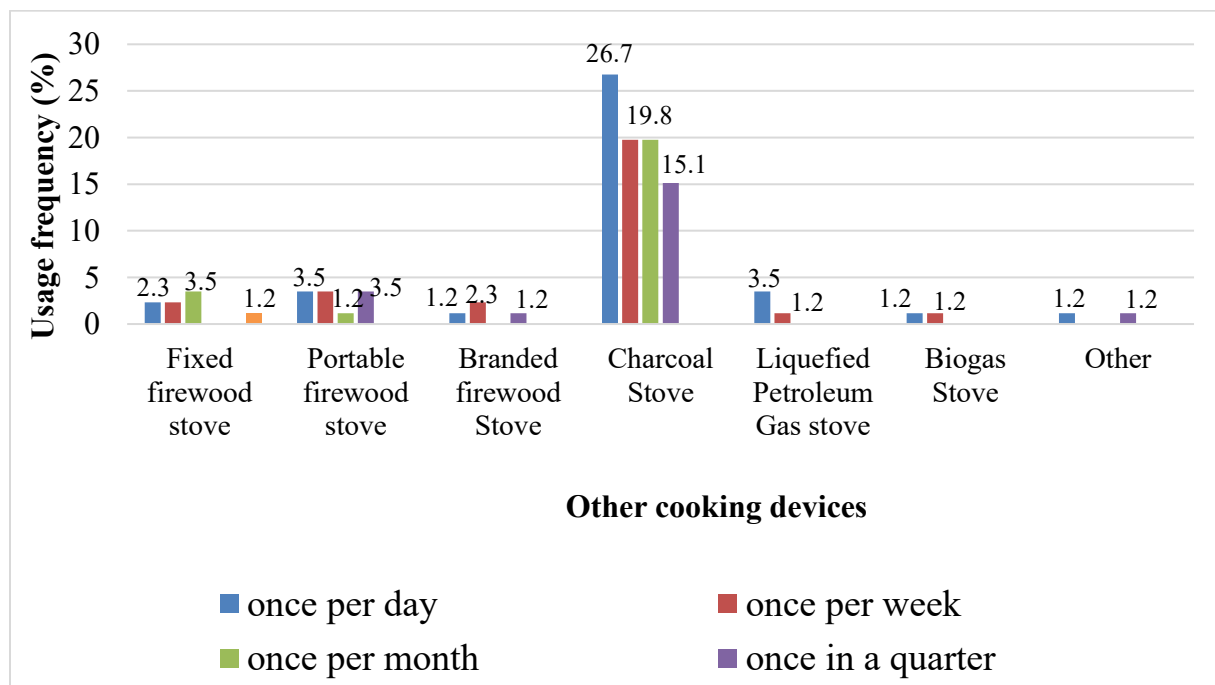


Figure 4.12: Frequency of the other cooking devices usage

Source: Researcher (2024).

Figure 4.12 indicates that the other cooking devices available in the households were used at least once every day with charcoal stove being the one used frequently by most of the households. Evidently, a significant number of households in Siaya County use more than one cooking device in their daily cooking routine. The presence of other cooking devices in the households (stove stacking) also came out from the key informant interviews. One of the interviewees remarked:

“Many of the households have a number of cooking devices which they simultaneously use based on the time of cooking, type of meal to be prepared, perceived stove efficiency, and the available fuel thereby hindering consistent use of a particular energy efficient device and making it difficult to track the usage rate”.

This means that sustained usage of any adopted energy efficient stove is a function of the whole cooking system taking into account the dynamic interaction between stove technology, fuels, users and the wider socioeconomic contexts. The result concurs with Joon *et al.* (2009) that complete substitution of traditional cooking devices with modern stoves is not always the case, further reinforcing the stove stacking theory which explains the use of multiple cooking devices in satisfying a particular household energy need. Likewise, Masera *et al.* (2015) posits that transitioning from traditional cooking devices has proven difficult, presenting the need for integrating approaches that incorporate deeper understanding of local needs and practices.

4.4 Factors that Influence Sustained Usage of the Energy Efficient Firewood Stoves by Households in Siaya County

The second objective of the study sought to determine the social, cultural, economic and technological factors that influence sustained usage of the energy efficient firewood cook stoves by households in Siaya County. Data was collected through survey in 399 households that had adopted the energy efficient cook stove (twin brick rocket) and from key informant interviewees. Descriptive and inferential statistics were jointly used to analyze the data and the findings were as presented and discussed in the subsequent sections.

4.4.1 Sociocultural Factors Influencing Usage of the Energy Efficient Cook Stoves

The social characteristics of the households including gender, age, education level, and household size were descriptively analyzed as well as correlated with the energy efficient firewood cook stove usage to achieve the results in Table 4.6.

Table 4.6: Social factors and the energy efficient stove usage

Efficient stove usage	Gender	Age	Education level	Household size
Pearson Correlation	-.038	-.039	-.037	-.014
Sig. (2-tailed)	.443	.437	.464	.778
N	399	399	399	399

Source: Researcher (2024).

4.4.1.1 Gender and stove usage

Table 4.6 demonstrates a weak negative correlation between gender and stove usage, although the relationship is not significant (Pearson's correlation coefficient = -0.038 and 2-tailed significance value = 0.443).

Descriptive analysis of the relationship between gender and stove usage was as in the Figure 4.13.

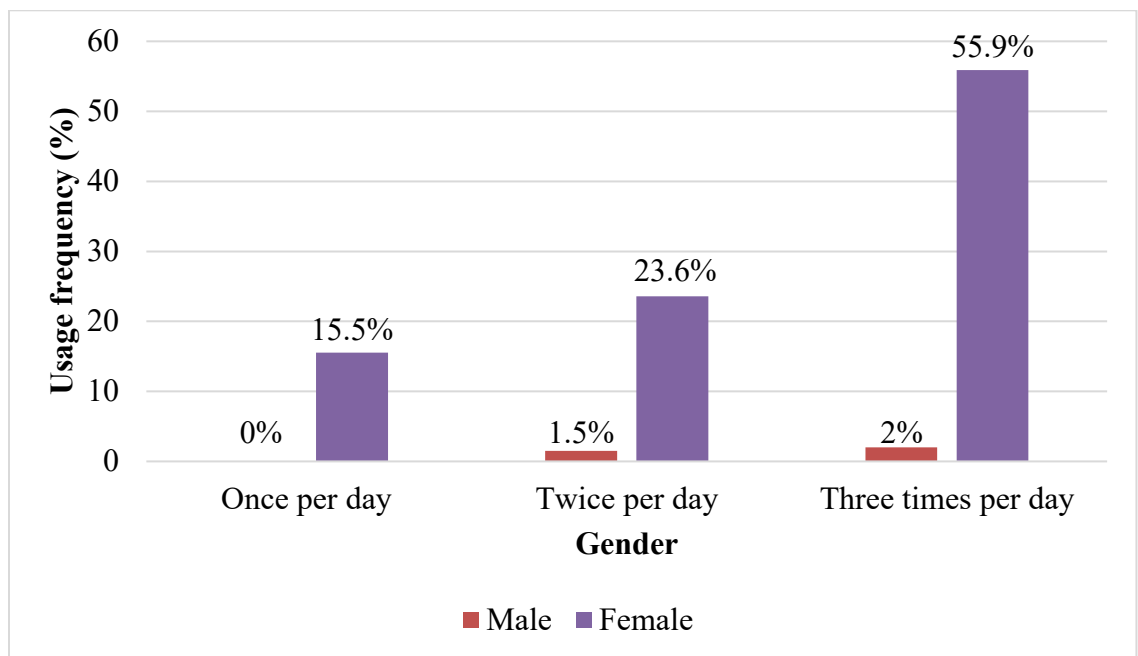


Figure 4.13: The energy efficient stove usage by gender

Source: Researcher (2024).

Figure 4.13 indicates that no male used the energy efficient stoves once per day but 1.5% of the males used the stoves twice daily while 2% used the stoves three times per day. The proportion of males using the stoves increased with daily usage frequency. Similarly, the proportion of females using the stoves increased with usage frequency where 15.5%, 23.6% and 55.9% respectively used the stoves once, twice and three times per day. The trend was

generally the same for both the male and female stove users. Based on the result it was concluded that there is no significant influence of gender on the stove usage. However, this conclusion disagreed with finding by Brooks *et al.* (2016) that households headed by a female are more likely to adopt and use improved cook stoves. It also contradicts assertion by one of the key informant interviewees that “*cooking is culturally the females’ responsibility in Siaya County so it is highly likely that the females use the energy efficient firewood cook stoves more than men*”.

4.4.1.2 Age and stove usage

Figure 4.14 presents the stove usage in terms of the users’ age category.

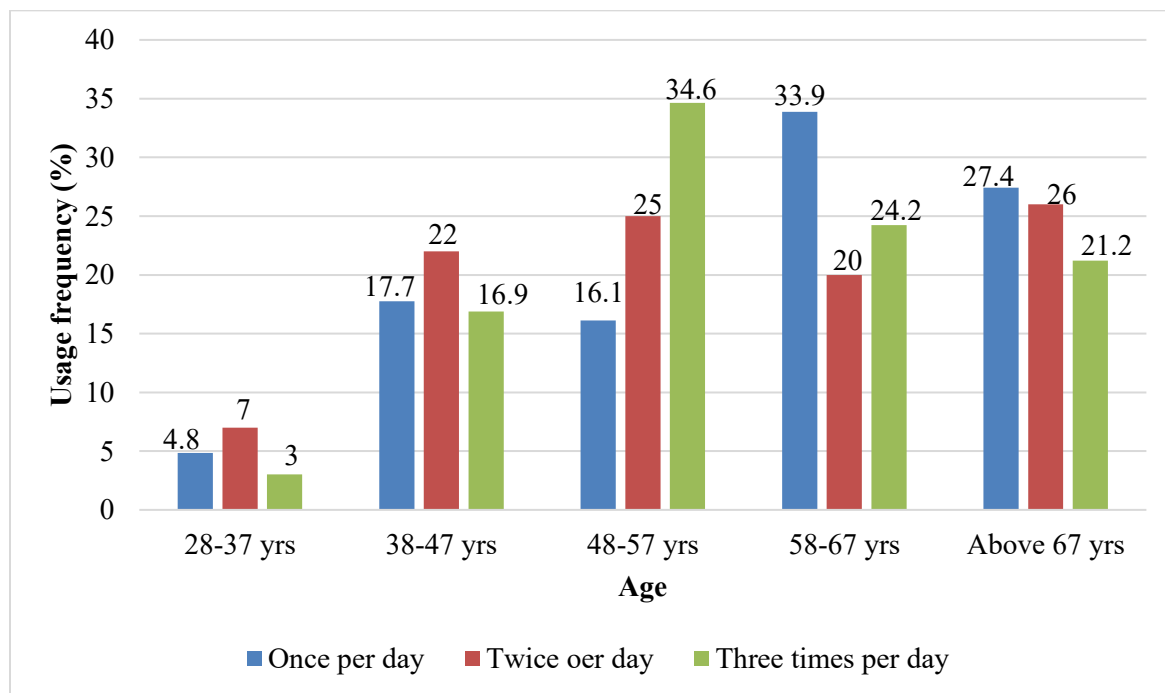


Figure 4.14: The energy efficient stove usage by age

Source: Researcher (2024).

From Figure 4.14, those in the age groups 28-37 years and 38-47 years mostly used the energy efficient stove twice a day. Those aged 48-57 years mostly used the energy efficient stove three times per day. Those aged 58 years and above mostly used the energy efficient stove once per day. Apparently, there was no particular trend in terms of the user's age relates with the energy efficient stove usage. The usage frequency kept fluctuating across the ages.

From Table 4.6, a Pearson's correlation of -0.039 and P-value of 0.437 implies an insignificant weak negative correlation between stove usage and age (the frequency of using the energy efficient cook stove insignificantly decreases as the user's age increases). This finding agrees with Jan *et al.* (2017) that reported no significant correlation between the age of the household head and the adoption and use of improved cook stoves. In terms of the direction of the insignificant correlation, this result confirms the findings by Lewis and Pattanayak (2012) that found a negative relationship between the age of the household head and the adoption and usage of improved cook stoves.

4.4.1.3 Education level and stove usage

The energy efficient stove usage in terms of the users' education level was as shown in Figure 4.15.

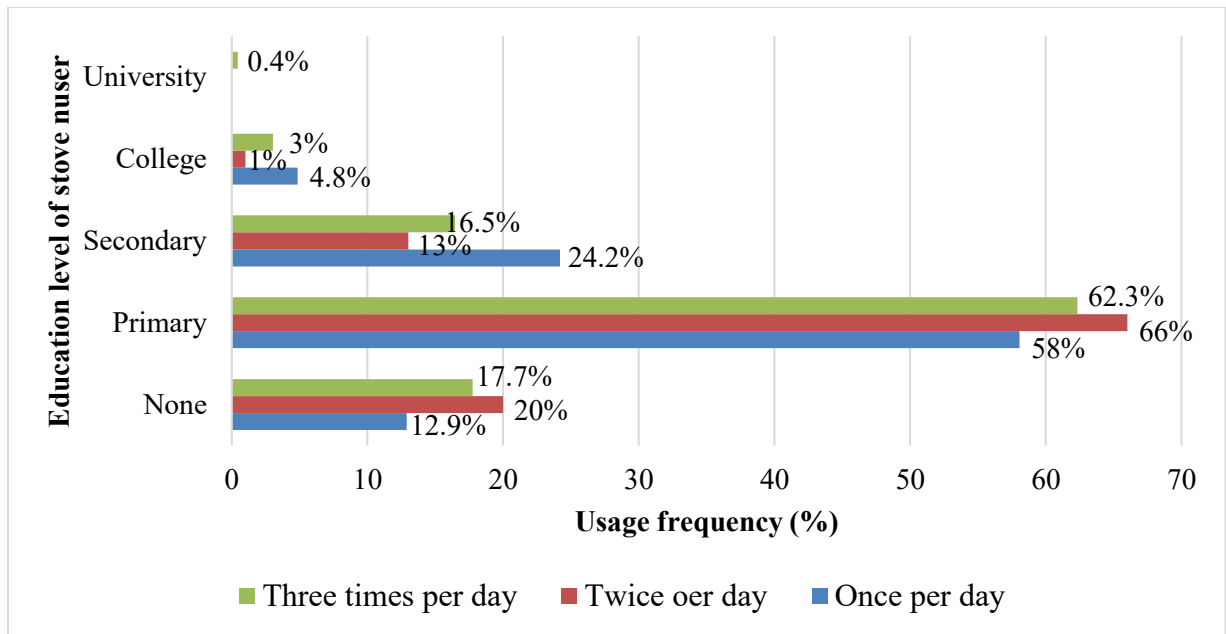


Figure 4.15: The energy efficient stove usage by education level

Source: Researcher (2024).

From Figure 4.15, those who had college and secondary level of education mostly used their twin brick rocket energy efficient firewood cook stoves once per day. The frequency of using the stove increased among users with primary level or no formal education as they used their stoves mostly two times or three times per day. The general trend is that frequency of using the energy efficient cook stove decreased with increase in education level. While it was expected that higher levels of education would translate to higher usage rate of the energy efficient cook stoves, this seemed not be the case. This finding concurs with a study by Troncoso *et al.* (2007) conducted in rural Mexico that found out that the number of years spent in school may not influence adoption and usage of a particular type of improved cook stove. Possibly, with increased education, the users become more open minded and progressive enough to access other alternative efficient stoves that they simultaneously use noting that the practice of stove stacking also came out in section 4.3.3

of this thesis. Perhaps the chances of a household accessing and simultaneously using multiple energy efficient stoves increase with increased level of education. However, this accesses may not necessarily translate to the sustained usage of a particular energy efficient stove by households with high education levels.

Moreover, Table 4.6 depicts a weak and insignificant negative correlation between education level of the stove user and stove usage as the Pearson's correlation coefficient is -0.037 and significance value Sig. (2-tailed) is 0.464. The conclusion is that education level has no significant influence on the energy efficient firewood cook stove usage. The negative direction of the insignificant relationship concurs with a study in rural Tanzania by Kulindwa *et al* (2018) that observed a negative correlation between education level and adoption and usage of improved cook stoves. Nonetheless, it contrasts with studies by Kong'ani *et al.* (2019) in Kiambu, Kenya, Vigolo *et al.* (2018), Jan *et al.* (2017) in rural Pakistan, Wilson *et al* (2016) in Darfur Sudan and Pundo *et al.* (2006) that found positive correlation between education level and stove adoption and usage (the more educated the stove user is, the more the household would use cleaner cooking technologies).

4.4.1.4 Household Size

Table 4.6 demonstrates a weak and insignificant negative correlation between household size and stove usage given the Pearson's coefficient equal to -0.014 and a 2-tailed significance value equal to 0.778. The depicted no significant correlation between household size and stove usage concurs with that of a study by Mamuye *et al.* (2018) in Dodola Ethiopia, which demonstrated that household size has no influence on the adoption and usage of improved cook stoves. In terms of the direction of the relationship,

the result agrees with both Mohapatra and Simon (2017) who reported a negative correlation between household size and adoption of improved cook stoves and Nyandie (2017) in Busia Kenya that observed smaller households to be adopting and using improved cook stoves more than larger ones.

4.4.1.5 The households' cooking practices and culture

The influence of the households' cooking practices and cultural beliefs on the energy efficient cook stove usage was also evaluated. When the respondents were asked under what circumstances they still had to cook on the old three stone open fire, the responses were as shown in the Figure 4.16.

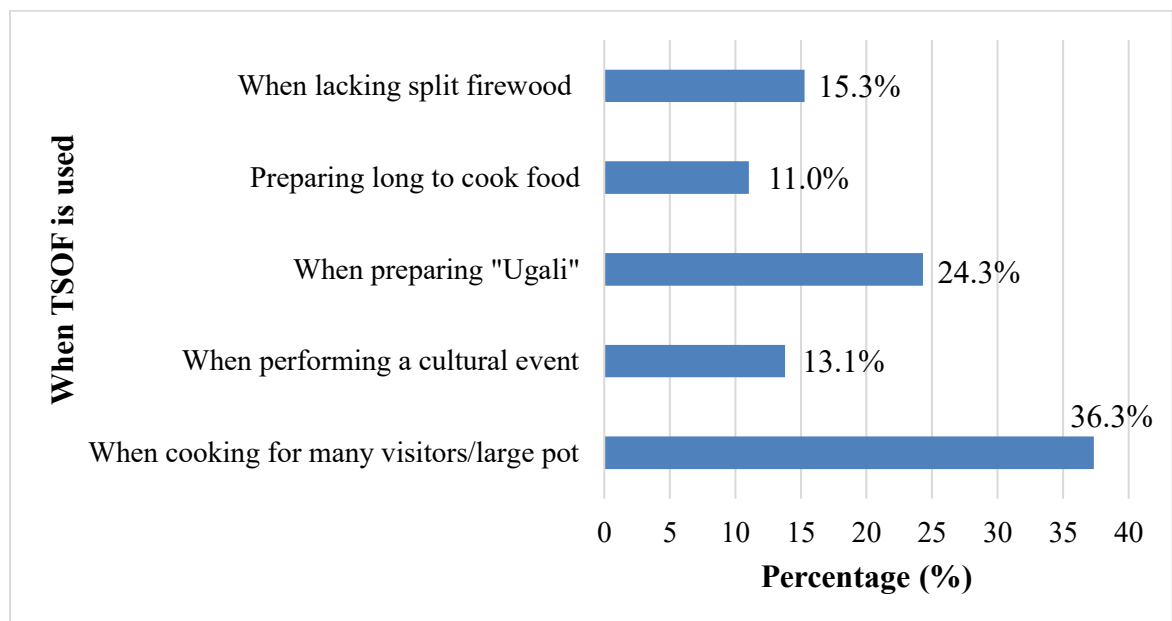


Figure 4.16: Circumstances under which old three stone open fire is still used

Source: Researcher (2024).

From Figure 4.16, of the households that still had to use their three stone open fire, 145 (36.3%) used the old stove when cooking for many visitors. 97 (24.3%) use the three stone

to prepare “*Ugali*” - a local bread made from corn, sorghum or millet flour - whose cooking pot needed to be held firmly when being prepared. 55 (13.8%) of the households used the three stone open fire when performing a cultural event.

Here, cooking practices and cultural beliefs influenced the energy efficient cook stove usage. Some of the cultural practices included cooking for visitors which is a common practice in the study area where holding of ceremonies is part of culture. Also, there were particular foods like “*Ugali*” that some of the households still had to cook on the three stone open fire. Importantly, the three stones used in open fire represented the family unit of father, mother and children hence using the three stone open fire had great significance when performing cultural events in this community. Moreover, that the households used the three stone open fire when they lacked split firewood, also points to the culture of collecting any readily available biomass including twigs from the surrounding which is mainly perceived not suitable for use on the energy efficient cook stove.

Some of these findings concur with those of other previous studies. For instance, IEA (2006) also reported that Indian households preferred to use wood cook stoves for baking traditional bread. Likewise, in rural Mexico Masera *et al.* (2000) found out that even people that could afford to use cleaner fuels continued to use fuel wood because it was more time consuming to cooking "tortillas" (a thin, unleavened bread made from wheat flour or maize hominy meal) on LPG.

4.4.2 Economic Factors Influencing Usage of the Energy Efficient Cook Stoves

The economic factors analyzed were the average household income and the cost of the stove. The average household income was descriptively analyzed as well as correlated with the energy efficient stove usage while cost related factors were only analyzed descriptively.

4.4.2.1 Average Household Income and Stove Usage

Figure 4.17 presents the stove usage frequency classified according to the average monthly income for the surveyed households.

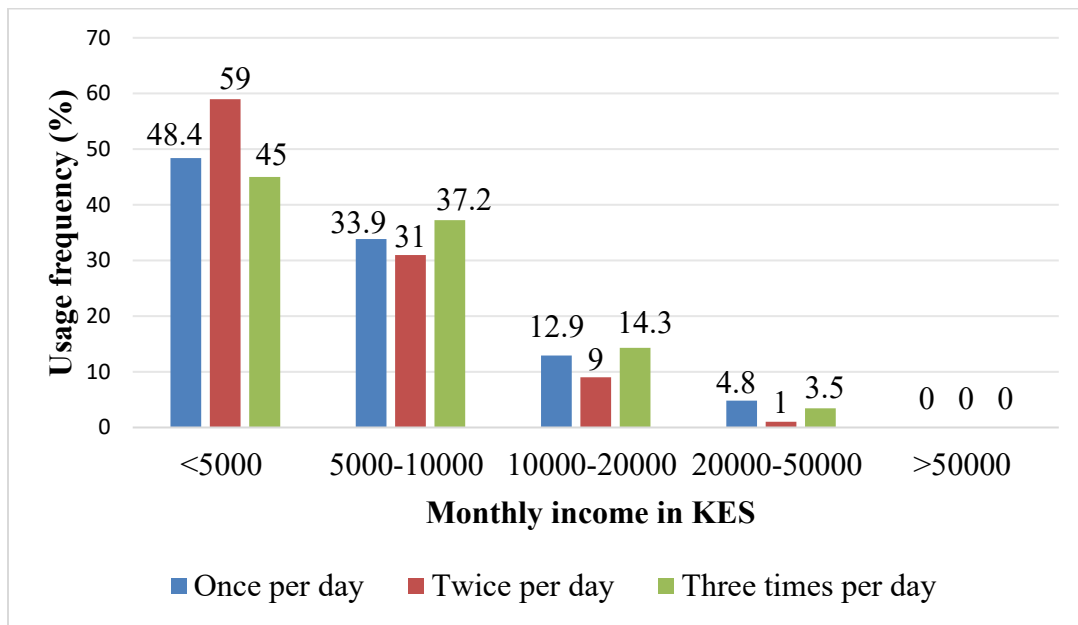


Figure 4.17: The energy efficient stove usage frequency based on household income
Source: Researcher (2024).

From Figure 4.17, more households whose monthly income falls between KES 5,000 and 20,000 mostly used the energy efficient cook stoves three times per day. In contrast, households with monthly income less than KES 5,000 mostly used the stoves twice per day. While the observable general trend is that increase in household income could be

associated with frequent usage, the trend was only clear among households with monthly income between KES 5,000 and 20,000 but changed for those having monthly income less than KES 5,000 and above KES 20,000. Households with monthly income of KES 20,000 to 50,000 mostly used the energy efficient stove once daily. Possibly, higher levels of income gave the households the option to simultaneously use other forms of clean cooking energy like charcoal or liquefied petroleum gas, as Vigolo *et al.* (2018) also found out.

A correlation between the household income and stove usage yielded result presented in the Table 4.7.

Table 4.7: Household income and the energy efficient stove usage

Efficient stove usage	Household income
Pearson Correlation	.054
Sig. (2-tailed)	.283
N	399

Source: Researcher (2024).

As shown in Table 4.7, the Pearson’s correlation coefficient of 0.054 and P-value of 0.283 indicates a moderately positive but insignificant correlation between the household income and stove usage. The conclusion is that while household income could possibly influence stove usage the correlation is not significant. However, the direction of this insignificant correlation confirms the findings by Onyeneke *et al.* (2019) in River State Nigeria and Pine *et al.* (2011) in rural Mexico which reported positive correlation. However, it differs with result of a study by Nyandie (2017) that observed a negative correlation between household income and use of improved cook stoves.

4.4.2.2 Cost of the energy efficient stove and usage frequency

The cost factors considered in the analysis included the stove purchase price, purchase experience and after purchase services, as shown in the Figure 4.18.

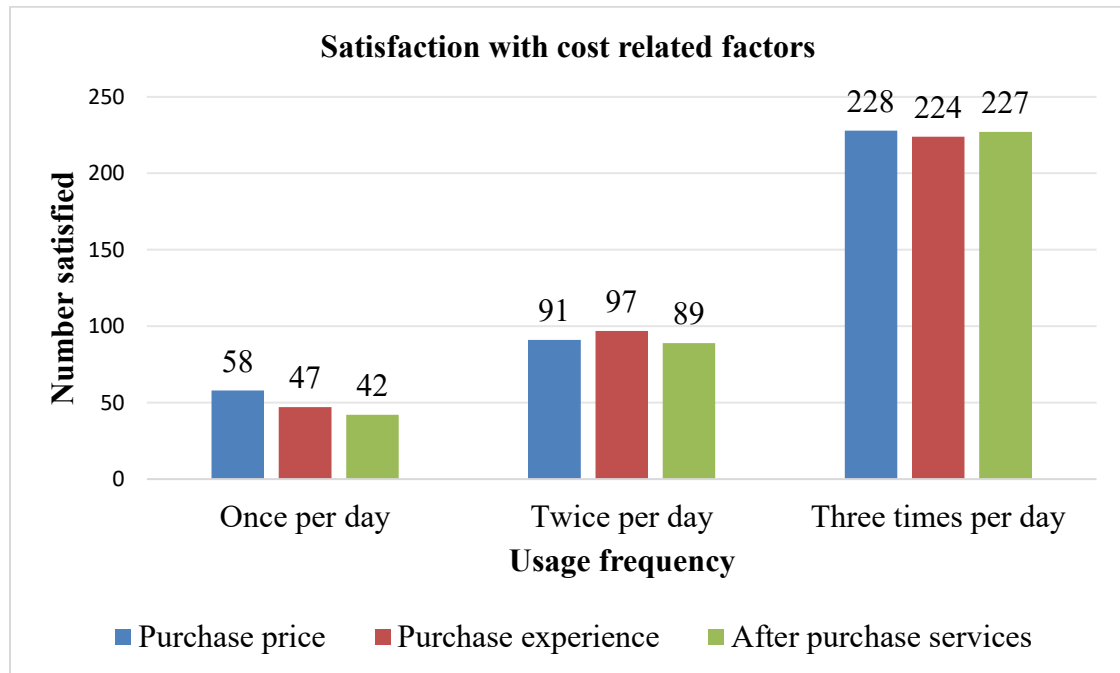


Figure 4.18: The efficient stove users' satisfaction with the cost related factors

Source: Researcher (2024).

From Figure 4.18, 228 (57.1%) households satisfied with the energy efficient firewood cook stove's purchase price, 224 (56.1%) satisfied with purchase experience and 227 (56.9%) satisfied with after purchase services used the stove three times per day. Conversely, 58 (14.5%) households satisfied with the energy efficient stove's purchase price, 47 (11.8%) satisfied with purchase experience and 42 (10.5%) satisfied with after purchase services used the stove once per day. This implies that the more the households were satisfied with the cost related factors the more frequently they used the efficient stove. It was therefore concluded that the cost related factors influence an efficient stove usage

rate. A similar study conducted in Ethiopia by Mamuye *et al.* (2018) found that the price of an improved cook stove, considered to be expensive by household heads, was the reason they were not using the improved stoves. Also, just like Kulindwa *et al.* (2018) observation that a percentage rise in the price of improved cook stoves led to reduced stove purchases in rural Tanzania, Stevens *et al.* (2020) identified improved cook stoves' affordability as a major barrier to their use in Kenya.

4.4.3 Technological Factors Influencing Usage of the Energy Efficient Cook Stoves

The technological factors analyzed were the stove design, overall quality and efficiency based on usage experience and indoor air quality. Also, the influence of fuel availability on the stove usage was analyzed. The technological factors were mainly analyzed descriptively.

4.4.3.1 Stove Design and efficiency

The survey participants were asked if they were satisfied with the design of the efficient stove, its overall quality and usage experience or not. Those who responded that they were satisfied, grouped according to their daily cooking routine using the energy efficient firewood cook stove, were as in Figure 4.19.

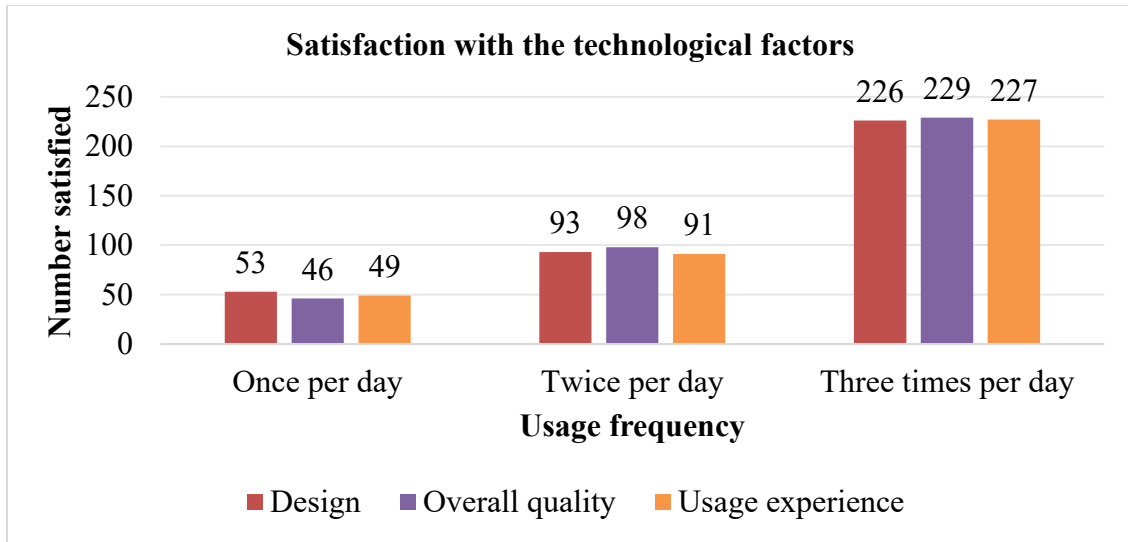


Figure 4.19: The stove users' satisfaction with design, overall quality and usage experience

Source: Researcher (2024).

From Figure 4.19, 226 (56.6%) households satisfied with their energy efficient stove's design, 229 (57.4%) satisfied with overall quality and 227 (56.9%) satisfied with usage experience used the energy efficient firewood cook stove three times per day. On the other hand, only 53 (13.3%) households satisfied with their energy efficient stove's design, 46 (11.5%) satisfied with overall quality and 49 (12.3%) satisfied with usage experience used the energy efficient firewood cook stove once per day.

Since the daily usage frequency increased with increase in the number of households satisfied with the design, overall quality and usage experience of the efficient stove, it was deduced that the stove design (looked at in terms of its height, size of fire chamber, pot rest, among other attributes), overall quality (the users' perception about durability, efficiency, ease of maintenance, among others) and usage experience positively influenced the frequency of the efficient stove usage. As Bensch *et al.* (2021) and Shen *et al.* (2014)

respectively found out, households use energy efficient firewood cook stoves over the three stone open fire because of their technological characteristics like higher combustion efficiency and fuel saving capability.

4.4.3.2 Improved air quality in the kitchen

When the households were asked if the air quality in the kitchen (indoor) had improved as a result of using the energy efficient stove, the result was as presented in Figure 4.20.

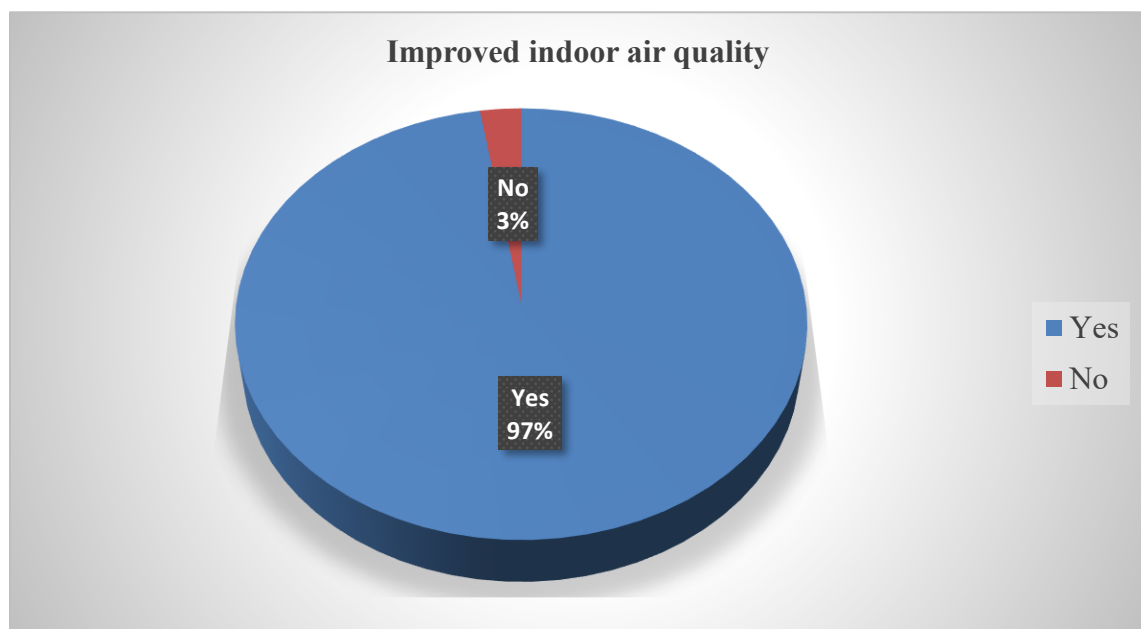


Figure 4.20: Improved air quality in the kitchen

Source: Researcher (2024).

From Figure 4.20, 387 (97%) of the households reported improved air quality in the kitchen as a result of using the energy efficient firewood cook stove (twin brick rocket).

When the respondents were further asked to state what according to them indicated that the air quality had improved in their kitchen, the result was as in Figure 4.21.

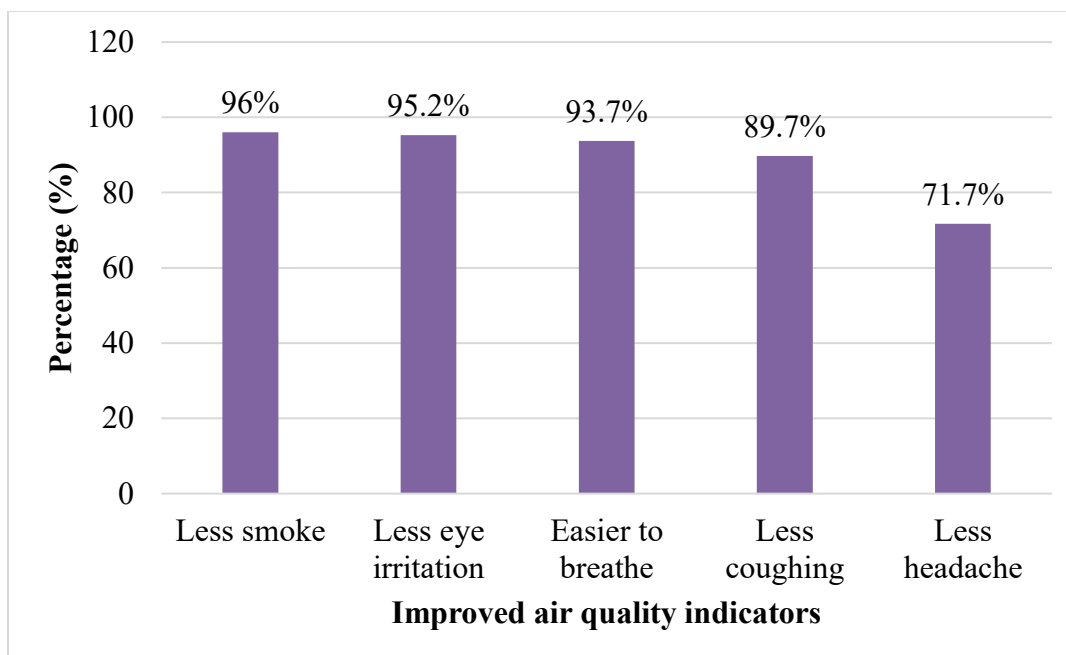


Figure 4.21: Indicators of improved air quality in the kitchen

Source: Researcher (2024).

From Figure 4.21, 383 (96%) felt that the air quality in their kitchen had improved because of less smoke produced when cooking with the energy efficient firewood cook stove. 380 (95.2%) experienced less eye irritation, 374 (93.7%) found it easier to breathe, 358 (89.7%) experienced less coughing and 286 (71.7%) experienced less headache when cooking with the energy efficient firewood cook stove.

When the households' perception on the indoor air quality improvement was compared with how frequently they used their energy efficient firewood cook stove (twin brick rocket), the result was as shown in Figure 4.22.

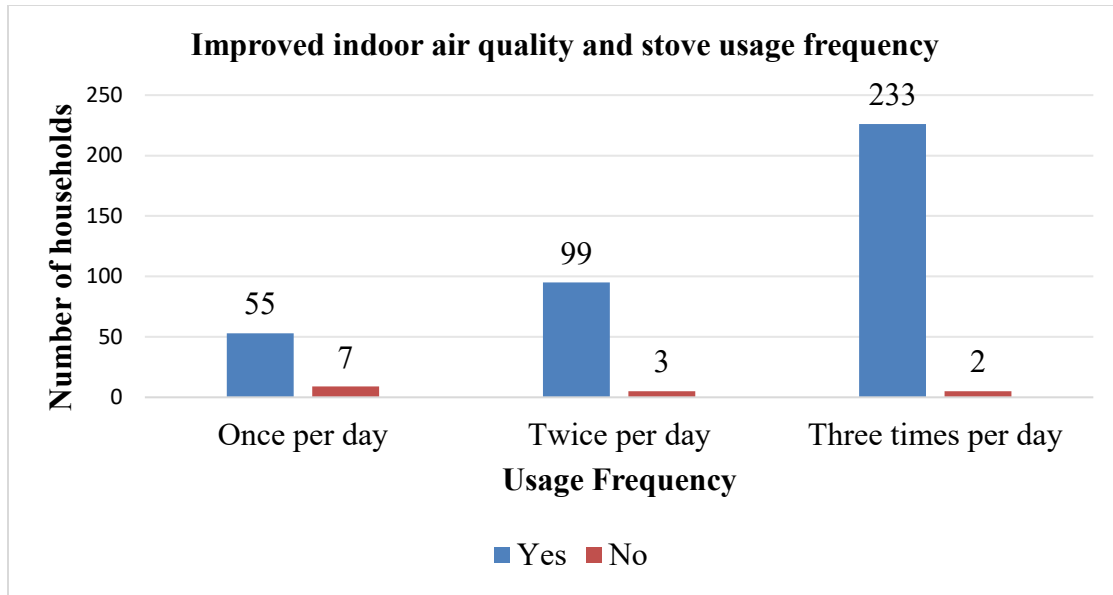


Figure 4.22: Improved air quality in the kitchen and efficient stove usage frequency
Source: Researcher (2024).

In Figure 4.22, 55 (13.8%), 99 (24.8%) and 233 (58.4%) of the respondents that agreed that air quality in their kitchen had improved respectively used the stoves once, twice and three times daily. On the other hand, for the respondents that did not experience improved indoor air quality 7 (1.8%), 3 (0.7%) and 2 (0.5%) respectively used the stoves once, twice and three times daily.

The households' perception on/experiences with the changes in the indoor air quality influenced the energy efficient stove usage. The frequency of using the energy efficient cook stove increased among the households who experienced improved indoor air quality while it decreased among those who did not experience improved indoor air quality.

It is expected that substitution of the traditional cooking devices results from the households' consideration of the new cooking device to be better than the traditional one based on the combustion efficiency. Figure 4.5 indicated that 290 (72.7%) of the surveyed

households were using the energy efficient stove because it produces less smoke which 96% of the households, as indicated in Figure 4.21, associated with improved indoor air quality.

4.4.3.3 Fuel Availability

Access to fuel was another important technological factor that was evaluated. The first step involved establishing the main fuel the households were using for cooking as shown in Figure 4.23.

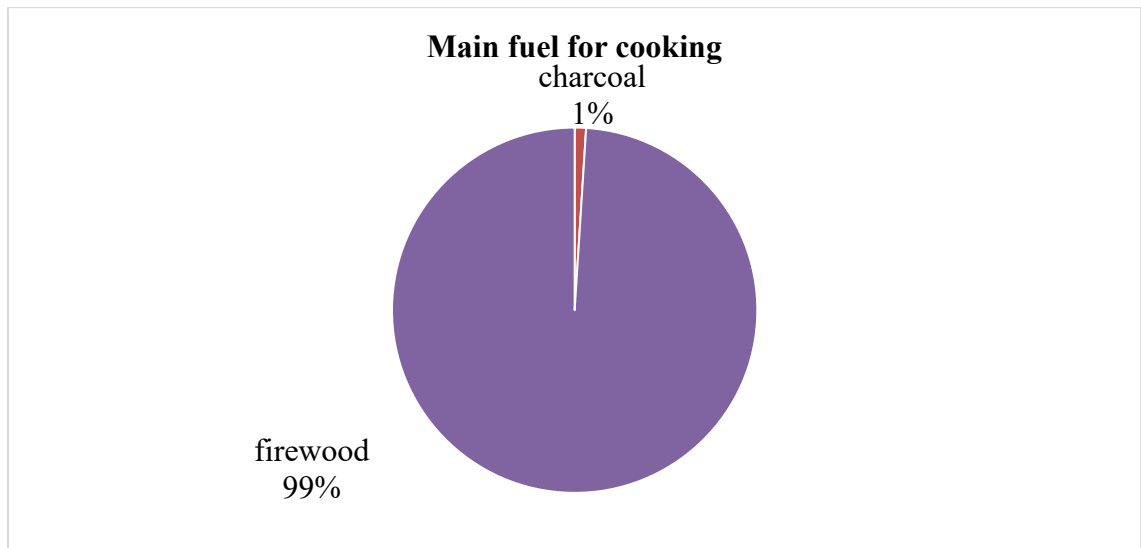


Figure 4.23: Main fuel used for cooking by the households

Source: Researcher (2024).

From Figure 4.23, 395 (99%) of the households were using firewood as their main fuel. Since the cost and accessibility of fuel determine its availability, how the households acquired the firewood being used was explored and the finding was as shown in Figure 4.24.

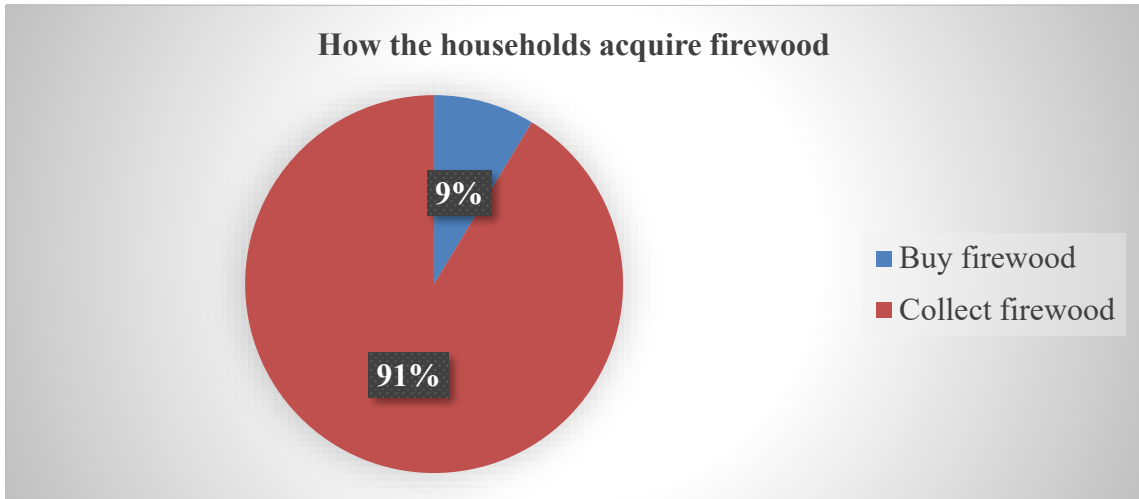


Figure 4.24: How the households acquire firewood

Source: Researcher (2024).

Figure 4.24 shows that firewood was acquired mainly through collection as 365 (91%) of the households collected firewood and only 34 (9%) bought firewood. When those collecting firewood were asked to state the firewood collection sites, they reported multiple sites (collection firewood from more than one site) as presented in Figure 4.25.

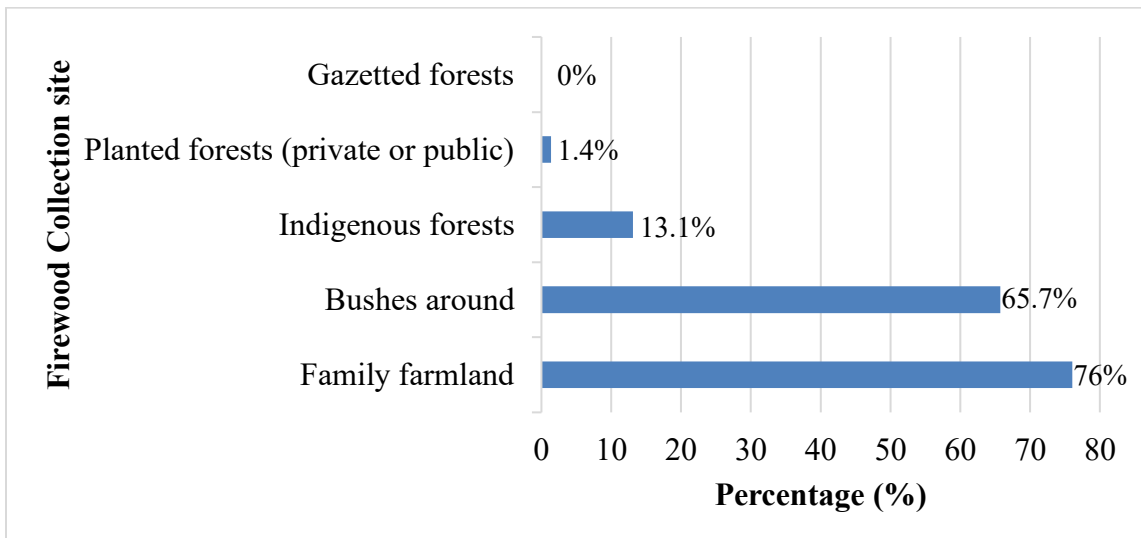


Figure 4.25: Firewood collection sites for the households

Source: Researcher (2024).

Figure 4.25 shows that the firewood collection sites for 303 (76%) and 262 (65.7%) households were family farmland and the surrounding bushes respectively. The implication of this result is that the households easily accessed the required cooking fuel. Exploring how the access to firewood related with the efficient stove usage, the finding was as in Figure 4.26.

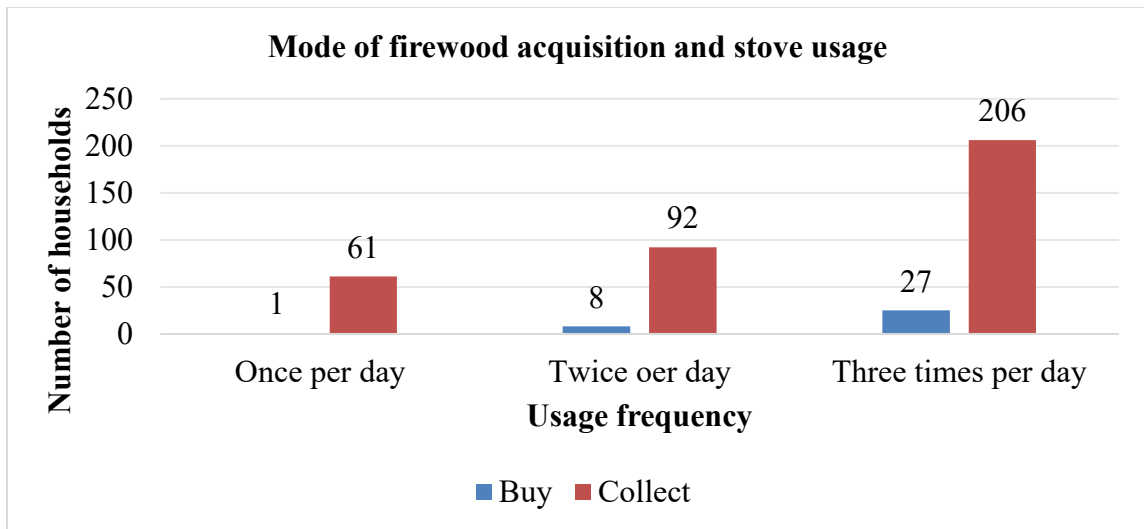


Figure 4.26: The mode of firewood acquisition and energy efficient stove usage frequency

Source: Researcher (2024).

Figure 4.26 indicates that frequency of stove usage increased regardless of whether firewood was bought or collected. This finding contradicts Mamuye *et al.* (2018) that households that obtain fuel at no cost, mostly by gathering and collection, tend not to be keen at using efficient cooking technologies. Similarly, it disagrees with Jagger and Jumbe (2016) that for fuel obtained at a cost, households would preferably use cooking technologies that achieve higher cooking efficiency with minimal fuel usage. Maybe, for the Siaya households the suitability of the fuel was more important a factor than the general

availability as earlier finding on Figure 4.7 indicated that lack of split firewood was a barrier for the consistent use of the twin brick rocket energy efficient firewood cook stove.

4.4.4 Testing the Hypothesis for Objective 2

In Tables 4.6 and 4.7, the results of the correlation between social and economic factors and the energy efficient stove usage had the significance level (P-values) for the stove users' gender, age, education level, household size and monthly income equal to 0.443, 0.437, 0.464, 0.778 and 0.283 respectively. The P-values were above the $P \leq 0.05$ threshold. The conclusion was that there is no significant influence of the socio-economic factors on sustained usage of the energy efficient firewood cook stoves by households in Siaya County. However, the descriptively analyzed technological and cultural factors were seen to have influence on sustained usage of the energy efficient stove.

4.5 The Relationship Between Sustained Usage of the Energy Efficient Firewood Cook Stoves and Climate Change Mitigation

The third objective of the study sought to determine the relationship between sustained usage of the energy efficient firewood stoves by households and climate change mitigation. The relationship was measured by quantifying and comparing firewood consumption and CO₂e emissions by both the energy efficient firewood cook stove (twin brick rocket) and the three stone open fire. The results were as presented and discussed in following sections.

4.5.1 Comparative Firewood Consumption

The energy efficient firewood cook stove's (twin brick rocket) climate change mitigation potential, measured by the change in CO₂e emission (ΔCO_2e) per unit of firewood the stoves helped save, was calculated based on changes in firewood consumption (ΔFC) relative to the three stone open fire. From the KPT data, taken in kilograms using calibrated digital weighing machines and converted into tonnes, daily and annual firewood consumption by both the three stone open fire and the energy efficient firewood cook stove were determined. Also, daily and annual firewood savings were determined. The findings were as presented and discussed in following sections.

4.5.1.1 Firewood consumption by three stone open fire

Based on the KPT data, total quantity of firewood consumed by all the 100 tested three stone open fire over the 7 days KPT period was 5.25 tonnes. Therefore, quantity of firewood consumed by a single three stone open fire over the 7 days KPT period was 0.0525 tonnes. Accordingly, the quantity of firewood consumed by a single three stone open fire per day was 0.0075 tonnes. In a year of 365 days the quantity of firewood consumed by a single three stone open fire was 2.7375 tonnes.

The recorded daily firewood consumption by a single three stone open fire of 0.0075 tonnes (7.5kg) was in between the values recorded by previous studies. While the value was slightly higher than 0.0067 tonnes (6.7kg) found out by Ochieng *et al.* (2013), it was slightly lower than the national daily fuelwood consumption range of 0.0083 tonnes (8.3kg) to 0.0105 tonnes (10.5kg) reported by Munyao *et al.* (2022) as well as that of Lung and Espira (2019) whose daily household firewood consumption by the traditional three stone

open fire was 0.00995 tonnes (9.95kg). The recorded daily firewood consumption was therefore realistic.

4.5.1.2 Firewood consumption by the energy efficient firewood cook stove (twin brick rocket)

Total quantity of firewood consumed by all the 100 tested efficient stoves over the 7 days KPT period was 3.08 tonnes translating to 0.0308 tonnes as the average quantity of firewood consumed by a single efficient stove over the 7 days KPT period. Per day, the quantity of firewood consumed by a single energy efficient firewood cook stove (twin brick rocket) was 0.0044 tonnes. Per year, the quantity of firewood consumed by a single energy efficient firewood cook stove (twin brick rocket) per year was 1.6060 tonnes.

Whereas the energy efficient firewood cook stove (twin brick rocket) recorded a lower daily firewood consumption compared to the results of previous studies, the daily fuel consumption of 0.0044 tonnes (4.4kg) was closer to 0.0054 tonnes (5.4kg) reported for a rocket stove by Ochieng *et al.* (2013). However, it was much lower than Munyao *et al.* (2022) that reported a daily per capita fuel consumption of 0.00188 tonnes (1.88kg) for mud rocket stove, that would translate to about 0.0094 tonnes (9.4kg) for Siaya County households with averagely 5 members established in this study. Perhaps, the contextual circumstances under which the studies were conducted could explain the difference in the fuel consumption.

4.5.1.3 Savings on the Firewood Consumption

The fuel savings was determined by calculating the difference between fuel consumption by the two stoves. The difference between the daily firewood consumption by a single three stone open fire that stood at 0.0075 tonnes and the 0.0044 tonnes of firewood consumed by a single energy efficient firewood cook stove was 0.0031 tonnes.

Annually, a single energy efficient firewood cook stove (twin brick rocket) saved 1.1315 (0.0031*365) tonnes.

Results of the comparative firewood consumption were as summarized in Table 4.8.

Table 4.8: Firewood consumption by twin brick rocket and three stone open fire

Firewood consumption	Firewood consumption by three stone open fire in tonnes	Firewood consumption by twin brick rocket in tonnes	Fuel Savings in tonnes	Percentage Fuel Savings (%)
Average Daily Consumption (tfirewood/day/stove)	0.0075	0.0044	0.0031	41.3
Average Annual Consumption (tfirewood/year/stove)	2.7375	1.6060	1.1315	41.3

Source: Researcher (2024).

Table 4.8 indicates that the three stone open fire consumes 2.7375 tonnes of firewood per year. The energy efficient twin brick rocket stove, on the other hand, consumes 1.6060 tonnes, ultimately saving 1.1315 tonnes (41.3%) of firewood per year compared to the traditional three stone open fire.

The interpretation of the 41.3% firewood savings is that rocket stoves can help conserve significant amount of firewood. Results from the household survey corroborated this KPT finding. When asked to compare the firewood consumption rate between the energy efficient firewood cook stove (twin brick rocket stove) and the three stone open fire, 100% of the respondents reported that from their cooking experience the twin brick rocket energy efficient firewood cook stove consumed less firewood as in Table 4.9.

Table 4.9: Firewood usage by the energy efficient stove and TSOF

Which stove consumes less firewood?	Frequency (f)	Percentage (%)
Twin brick rocket	399	100
Three stone open fire	0	100
N	399	100.0

Source: Researcher (2024).

Whereas the firewood savings rate of 41.3% is above the 30% fuel saving recommended by (Bailis, 2018) for such a study, the result is comparable with or is even lower than results from other previous similar studies. The result is closer to that of a study in Tanzania that found out that a household using three stone open fire consumes around 2.88 tonnes of firewood per year while improved firewood stove consumes 1.728 tonnes thereby reducing the firewood consumption by around 1.152 tonnes comprising 40% and equivalent to 20 trees saved per year (Njogu, 2011). Similarly, GIZ (2018) and Orlale and Odee (2013) reported that, if used properly with dry firewood, a fixed inbuilt household stove saves up to 40% of firewood compared to the three stone open fire.

Significantly, 41.3% fuel saving is lower than 43% established by Mekonnen (2022) for rocket stove. Bogale and Wondogenet (2020) compared fuel consumption between an improved mud stove locally called *Gonzeye* in Ethiopia with the traditional three stone open fire and reported that traditional three stone open fire consumed 0.201 tonnes of fuelwood per year compared with 0.0914 tonnes of fuelwood consumed by *Gonzeye* stoves comprising 54.5% fuel savings.

Despite the 30% recommendation, Bailis *et al.* (2018) also observes that many stove studies and programs have reported reductions in fuel consumption of 50% or more. Kamfor (2002), for instance, reported that rocket stoves can help conserve wood by over 60%. The firewood savings rate of 41.3% was therefore considered to be conservative.

4.5.2 Comparative CO₂e Emissions

The CO₂e emission was quantified by considering the number of days in a year the stove was in use (N), its cumulative usage rate (U) and daily firewood consumption in tonnes (t/day/stove). Other parameters used in the quantification were the fraction of non-renewable biomass fraction (f'NRB), the CO₂ emission factor for wood (EF wood, CO₂), non-CO₂ emission factor for wood (EF wood, nonCO₂). Emission leakage (LE) - whether the emissions reductions here was causing increase in emissions elsewhere - was also factored in.

For the three stone open fire, the estimated tonnes of carbon dioxide equivalent emitted was 3.4111 tCO₂e, as worked out below:

$$\begin{aligned}
E_{\text{tsof}} &= (N*U*t/\text{day}/\text{stove})*(NRBf*EF_{\text{wood, CO}_2}+EF_{\text{wood, nonCO}_2})-LE \\
&= (365*0.710*0.0075)*(0.92*1.7472+0.1476)-0 \\
&= 3.4111 \text{ tCO}_2\text{e}
\end{aligned}$$

The annual CO₂e emission by the energy efficient firewood cook stove (twin brick rocket), also quantified using the same parameters as in the case of three stone open fire but with values specific to the efficient stove, was 2.0012 tCO₂e as worked out below:

$$\begin{aligned}
E_{\text{tbrs}} &= (N*U*t/\text{day}/\text{stove})*(NRBf*EF_{\text{wood, CO}_2}+EF_{\text{wood, nonCO}_2})-LE \\
&= (365*0.710*0.0044)*(0.92*1.7472+0.1476)-0 \\
&= 2.0012 \text{ tCO}_2\text{e}
\end{aligned}$$

4.5.2.1 CO₂e Emission Reduction (ER)

The difference between the carbon dioxide equivalent (CO₂e) emissions by the three stone open fire and the energy efficient firewood cook stove (twin brick rocket) was calculated to determine the tonnes of carbon dioxide equivalent emission that could be reduced by using the efficient stove. Therefore:

Emission Reduction = Emission by three stone open fire - Emission by energy efficient firewood cook stove

$$ER = 3.4111 \text{ tCO}_2\text{e} - 2.0012 \text{ tCO}_2\text{e}$$

$$ER = 1.4099 \text{ tCO}_2\text{e}$$

The result indicates that using the energy efficient firewood cook stove (twin brick rocket) annually reduces 1.4099 tCO₂e (41.3%) emissions, compared to the three stone open fire. Comparatively, a study by Mekonnen (2022) reported 1.3 tCO₂e emission reduction per year by rocket stove over the three stone open fire. Also, when the survey respondents' opinion was sought on smoke emission by the two stoves, 98.5% of the surveyed

households reported that the energy efficient firewood cook stove produces less smoke when being used compared to the three stone open fire as shown in Table 4.10.

Table 4.10: Smoke emission by the energy efficient stove and TSOF

Which stove produces less smoke?	Frequency (f)	Percentage (%)
Twin brick rocket	393	98.5
Three stone open fire	6	1.5
N	399	100.0

Source: Researcher (2024).

Based on the reduction in firewood consumption and smoke (CO₂e) emissions, the interpretation can only be that sustained usage of the energy efficient firewood cook stove (twin brick rocket) positively affects climate change mitigation. Sustained usage of the energy efficient firewood cook stove would significantly contribute to cutting the greenhouse gases emission and enhancing the vegetation cover - a CO₂ sink that absorbs and stores the gas.

4.1.3 Testing the Hypothesis for Specific Objective 3

In testing the the hypothesis for specific objective 3 data from the household survey was used. When the twin brick rocket cook stove usage was correlated with both fuel consumption and smoke emission/air quality improvement in the kitchen, the finding was as depicted in Table 4.11.

Table 4.11: Relationship between the efficient stove usage, fuel consumption and less smoke emission

		Reduced fuel consumption	Less smoke emission
Twin brick rocket stove usage	Pearson Correlation	.108*	.019*
	Sig. (2-tailed)	.032	.047
	N	399	399

*. Correlation is significant at the 0.05 level (2-tailed).

Source: Researcher (2024).

The significance levels (p-values) for fuel consumption and indoor air quality improvements were reported as 0.032 and 0.047, respectively. These values fall below the $P \leq 0.05$ threshold, indicating that the observed effects are statistically significant and not likely due to chance. Hence, there is a statistically significant correlation between the use of energy efficient firewood cook stoves and both fuel consumption and less smoke emission or improved indoor air quality. This means that, based on collected data, the use of these stoves is associated with reduced fuel consumption and better air quality inside the kitchen due to reduced CO₂e emissions. As per these findings, we can deduce that adoption of energy efficient firewood cook stoves has a tangible impact on reducing fuel consumption and GHGs emissions thereby enhancing indoor air quality.

The energy efficient stoves are a likely beneficial intervention for climate change mitigation. Reduced fuel consumption translates to decreased demand for firewood, potentially lowering forest degradation. Hosonuma *et al.* (2012) reports that high demand for wood fuel can contribute to forest degradation. Forest degradation reduces the ability

of the forests to sequester and store carbon (Jandl *et al.*, 2007), negatively impacting climate change mitigation.

Besides, the stoves' high combustion efficiency reduces GHGs emissions. From this study approximately 1.1315 tonnes of firewood translating to a reduction of CO₂e by 1.4099 tonnes could be achieved through the use of a single twin brick rocket energy efficient firewood cook stove in a year. Drawing from TaTEDO (2005) cited in Njogu (2011) an equivalent of 20 trees would be saved by consistently using a single twin brick rocket per year. If all the 127,242-twin brick rocket cook stoves so far installed were to be consistently used, then approximately 2,544,840 trees could be saved per year in Siaya County. Over, the stoves minimum lifespan of five years, approximately 12,724,200 trees would be conserved.

Therefore. the null hypothesis: *There is no significant relationship between sustained usage of the energy efficient firewood cook stoves by households and climate change mitigation in Siaya County* was rejected.

CHAPTER FIVE

SUMMARY, CONCLUSIONS AND RECCOMENDATIONS

5.1 Summary of the Study Findings

5.1.1 The Usage Rate of the Energy Efficient Firewood Cook Stove in Relation to the Other Stoves in Siaya County

The study determined the usage rate of the energy efficient firewood cook stove (twin brick rocket) in relation to the other stoves including the old three stone open fire as well as any other cooking devices used by the households in Siaya County. The key study findings were that 96.4% of the installed energy efficient firewood cook stove was generally in use because it retains heat, uses less firewood and produces less smoke although the usage was not entirely consistent. However, the energy efficient firewood cook stove (twin brick rocket) was not being used consistently.

Comparing the households' normal cooking pattern and the frequency of the energy efficient firewood cook stove usage revealed that 20.6% of the households who normally cooked three times every day did not use the energy efficient stove every time they were cooking. Also, 14% and 6.6% of the households respectively cooked once and twice per day more on the energy efficient stove compared to their normal cooking pattern. The leading reasons for the inconsistent usage were technological in nature, including lack of split firewood with which the users felt the stove worked best, need for a large cooking surface and difficulty to light up the stove besides being considered to be cooking slowly by some households.

Also, a significant number of the households still used their old three stone open fire. 42.4% of the households still retained their old three stone open fire with 35.1% still in use with (22.1%) having been used every day in the past two weeks. The reasons for which the households used their old stove were mainly technological issues touching on stove design, efficiency and fuel availability as well as sociocultural ones including the number of people to be cooked for and the type of food to be cooked.

Besides, 21.6% of the households had other cooking devices including other firewood, Charcoal, LPG and Biogas stoves which they used alongside the energy efficient firewood cook stove and/or the three stone open fire, with charcoal stove being the other most popular cook stove. The use of more than one cooking device (stove stacking) was confirmed by one of the key informant interviewee's remark that:

“Many of the households have a number of cooking devices which they simultaneously use based on the time of cooking, type of meal to be prepared, perceived stove efficiency, and the available fuel thereby hindering consistent use of a particular energy efficient device and making it difficult to track the usage rate”.

5.1.2 The Sociocultural, Economic and Technological Factors that Influence Sustained Usage of the Energy Efficient Firewood Cook Stoves by Households in Siaya County

From the study, the significance level (P-values) for the social and economic factors including stove users' gender, age, education level, household size and monthly income equal to 0.443, 0.437, 0.464, 0.778 and 0.283 respectively, were above the $P \leq 0.05$ threshold implying they all had no significant influence on the sustained usage. However, from the descriptively analyzed results, the cost of the stove which is an economic factor seemed to influence the stove's sustained usage as the more satisfied the households were with the cost factors the more frequently, they used the efficient stove. 56.6% of the households satisfied with the energy efficient stove's purchase price, purchase experience and after purchase services used the stove three times every day.

By the same token, cultural cooking practices influenced the energy efficient cook stove usage. There were particular foods and circumstances under which some of the households still had to cook on the three stone open fire. 24.3% used the three stone to prepare "*Ugali*" - a local bread made from corn, sorghum or millet flour - whose pot needs to be held firmly when being prepared to have a good taste. 13.8% used the three stone open fire when performing a cultural event while 36.3% used the old stove when cooking for many visitors (a common cultural practice in study area).

Also, technological factors including the stove design, efficiency, fuel availability and air quality in the kitchen seemed to influence the efficient stove usage. Those who used the energy efficient firewood cook stove (twin brick rocket) did so due to the stove's

technological capacity to retain heat, consume less firewood and produce less smoke. Daily usage frequency increased with increase in the number of households satisfied with the design, overall quality and usage experience of the efficient stove. 58.4% of those who believed the efficient stove improved the indoor air quality in their kitchen used the stoves three times daily.

Generally, the reasons for which the households inconsistently used the energy efficient firewood cook stove or still used the three stone open fire were technological in nature. 23.9% of the households did not consistently use the energy efficient cook stoves due to lack of split firewood with which they felt the stove worked best. Respectively, 19.6% and 17.8% households did not consistently use the efficient stove when they required a large cooking surface and because the efficient was difficult to light up. Another 16.6% did not use the stove when cooking for many visitors. 9.8% also felt that the energy efficient firewood cook stove cooked slowly and 3% did not consistently use the stove when preparing long to cook food. On the other hand, 25.4% used the TSOF because they lacked split firewood, for 24.6% TSOF allowed for enlarging the cooking surface and 15.9% used it when preparing meals for many visitors. 15.1% felt that the TSOF was more suitable for foods that took long to cook. Households that used the TSOF because they felt it cooked faster and was easy to light up each stood at 9.5%.

5.1.3 The Relationship Between Sustained Usage of the Energy Efficient Firewood Cook Stoves and Climate Change Mitigation in Siaya County

Finally, this study established that a single twin brick rocket energy efficient cook stove could save approximately 1.1315 tonnes of firewood translating 1.4099 tonnes of CO_{2e} comprising 41.3% per year compared to the three stone open fire. The reduced firewood

consumption enhances carbon sink through increased vegetation cover while reduced GHGs emission implies reduced greenhouse effect. At this rate, consistently using a single twin brick rocket could help conserve about 20 trees per year. Sustained usage of the energy efficient firewood stoves by households positively affected climate change mitigation.

5.2 Conclusion

The study concluded that:

- i. About one fifth of the households who have adopted energy efficient firewood stoves in Siaya County do not consistently use the adopted stoves, about a third still falling back to use their old TSOF and about one fifth simultaneously using different cooking devices.
- ii. Socio-economic factors including gender, age, education level, household size and monthly income of the the stove user do not have significant influence on sustained usage of the energy efficient firewood cook stove. However cultural factors including preparing particular local foods like “*Ugali*” and cooking for many visitors; economic factors including cost of the stove; and technological factors including the stove design, available fuel option and perceived efficiency seemed to have influence on the energy efficient stove’s sustained usage.
- iii. There is a significant relationship between sustained usage of the energy efficient firewood cook stoves and climate change mitigation as the stove remarkably reduce firewood consumption and GHGs emissions.

5.2.1 Overall Conclusion

The overall conclusion of the study was that despite the climate change mitigation benefits associated with the energy efficient firewood cook stove's sustained usage, many households in Siaya still inconsistently used it and continued to use the inefficient TSOF mainly due to technological and cultural factors.

5.3 Recommendation

Informed by the findings, the study recommends that:

- i. Since a good proportion of the households' relapse to using their old three stone open fire there is need for enhanced community awareness campaigns on the benefits of using the energy efficient firewood cook stove (twin brick rocket) and the households be better trained on stove usage noting that 17.8% of the households did not consistently use the efficient stove because it was hard to light up.
- ii. In a bid to sustain usage of the energy efficient firewood cook stoves, its promotion should integrate approaches that allow deep understanding of context-specific sociocultural, economic and technological factors as well as monitoring usage rates including residual usage of the traditional three stone open fire. Probably, the energy efficient firewood cook stove (twin brick rocket) be improved or redesigned in such a manner to allow its usage with any type of firewood (readily available firewood) including twigs since 23.9% of the energy efficient firewood cook stoves were not consistently being used due to lack of split firewood. Also, the stove should be able to satisfy the need for a large cooking surface whenever it arises. While the stove is designed with two cooking units of different sizes to accommodate a range of cooking

pots in a particular household, this seems not to be effectively working as 19.6% of the households did not use the energy efficient firewood cook stove (twin brick rocket) when they needed a large cooking surface.

- iii. The usage of the energy efficient firewood cook stove (twin brick rocket) by the households should be sustained to maximize on the climate change mitigation benefits including reduction of CO₂e emissions and firewood consumption for enhanced carbon sink.

5.2.1 Recommendation for further research

This study recommends that future studies may consider:

- i. Adopting the use of stove use monitoring system (SUMS) to compare or contrast the results of the stoves' usage rate from this study which mainly relied on household response and interviewer observation to determine the usage rate.
- ii. Evaluating the effect of firewood extraction on the tree cover in the County which was beyond the scope of this study. Limited data exist to back the claim that extraction of wood for cooking has over the years contributed to the continuous dwindling of the area under vegetation cover in Siaya, the County with the least forest cover in Kenya, pointing to the need for further research on the same.

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Appendix I: Images Taken During Data Collection



Left: Interview with one of the households with twin brick rocket stove

Right: Household visited during Kitchen Performance Test (KPT)



Left and Right: Twin brick rocket stove being used in the households surveyed



Left: Firewood sourced from a vendor for the Kitchen Performance Test (KPT)

Right: Firewood being weighed at one of the households during the KPT



Three Stone Open Fire (TSOF) being used in one of the households surveyed

Appendix II: Household Questionnaire

Dear Respondent,

My name is **Victor Omondi John**, a Master of Science in Climate Change Mitigation and Adaptation student from Masinde Muliro University of Science and Technology (MMUST). This is to request you to volunteer about 30 minutes of your time to take part in a study that evaluates the contribution of sustained usage of energy efficient firewood stoves to climate change in Siaya County. This is part of a process called “*informed consent*” allowing you to understand the study before deciding whether you can take part in it or not.

The information you provide will be useful to the study. The information obtained will remain confidential and will only be used for the purpose of this survey. Please note that you are free to accept or decline this request or even withdraw from the interview if you so wish without any penalty. Noteworthy, the study has no direct benefits to the respondents and there are no risks to your participation.

If you have any questions regarding the study, you can now ask.

Do you volunteer to participate? Yes No

A. Information on household/stove user	
1. Are you the primary cook or stove user?	<input type="checkbox"/> Yes <input type="checkbox"/> No
2. Gender	<input type="checkbox"/> Male <input type="checkbox"/> Female
3. Age	<input type="checkbox"/> Below 18 yrs <input type="checkbox"/> 18-27 yrs <input type="checkbox"/> 28-37 yrs <input type="checkbox"/> 38-47 yrs <input type="checkbox"/> 48-57 yrs <input type="checkbox"/> 58-67 yrs <input type="checkbox"/> Above 67 yrs
4. Education Level	<input type="checkbox"/> None <input type="checkbox"/> Primary <input type="checkbox"/> Secondary <input type="checkbox"/> College <input type="checkbox"/> University
5. Number of persons permanently living in the household	Adults (above 18 yrs)..... Children (below 18 years)..... Total:
6. Number of persons eating in the household	Adults (above 18 yrs)..... Children (below 18 years).....

	Total:
7. What is the household's main sources of livelihood	<input type="checkbox"/> None <input type="checkbox"/> Formal Employment <input type="checkbox"/> Crop farming <input type="checkbox"/> Casual Labour <input type="checkbox"/> Livestock farming <input type="checkbox"/> Others <input type="checkbox"/> If others, specify
8. What is the household's average total monthly income?	<input type="checkbox"/> Below 5000 KES <input type="checkbox"/> 5000-10000 KES <input type="checkbox"/> 10000-20000 KES <input type="checkbox"/> 20000-50000 KES <input type="checkbox"/> Above 50000 KES
B. Information on the cook stoves	
9. Do you have any energy efficient firewood stove? (Only those with any energy efficient firewood stove can be interviewed)	<input type="checkbox"/> Yes <input type="checkbox"/> No
10. If yes in 9 above, what is the type?	<input type="checkbox"/> Fixed stove; Specify..... <input type="checkbox"/> Portable stove; Specify..... <input type="checkbox"/> Branded Stove; Specify..... <input type="checkbox"/> Gasifier Stove; Specify..... <input type="checkbox"/> Any other (specify).....
11. How long has it taken since you purchased/installed the energy efficient cook stove?	<input type="checkbox"/> Less than 1 yr <input type="checkbox"/> 1 yr <input type="checkbox"/> 2 yrs <input type="checkbox"/> 3 yrs <input type="checkbox"/> 4 yrs <input type="checkbox"/> 5 yrs <input type="checkbox"/> 6 yrs <input type="checkbox"/> 7 yrs <input type="checkbox"/> 8 yrs <input type="checkbox"/> 9 yrs <input type="checkbox"/> 10 yrs <input type="checkbox"/> Over 10 years (specify)
12. What do you mainly use your stove for?	<input type="checkbox"/> domestic use (household cooking) <input type="checkbox"/> commercial use (fish frying, street kitchen,...) <input type="checkbox"/> both domestic and commercial uses
13. What was your main cook stove before you	<input type="checkbox"/> 3-stone open fire <input type="checkbox"/> Charcoal Stove <input type="checkbox"/> Gas stove

<p>purchased/installed the efficient cook stove?</p>	<p><input type="checkbox"/> Electric cooker <input type="checkbox"/> Kerosene stove <input type="checkbox"/> Any other (specify).....</p>
<p>14. Where is your old stove now, after you purchased/installed the efficient cook stove?</p>	<p><input type="checkbox"/> destroyed <input type="checkbox"/> still available, but not used <input type="checkbox"/> still available and still in use</p>
<p>15. If your old stove is still available and still in use, please indicate how often (normal cooking pattern in a year)</p>	<p><input type="checkbox"/> every day <input type="checkbox"/> every second day <input type="checkbox"/> once per week <input type="checkbox"/> every second week <input type="checkbox"/> once per month <input type="checkbox"/> once in a quarter</p>
<p>16. Please list all the cook stoves currently used by the household</p>	<p><input type="checkbox"/> 3-stone open fire <input type="checkbox"/> Fixed stove <input type="checkbox"/> Portable stove <input type="checkbox"/> Branded Stove <input type="checkbox"/> Gasifier Stove <input type="checkbox"/> Charcoal Stove <input type="checkbox"/> Gas stove <input type="checkbox"/> Electric cooker <input type="checkbox"/> Kerosene stove <input type="checkbox"/> Biogas stove <input type="checkbox"/> Any other (specify).....</p> <p>*****</p> <p>Interviewer's observation: Please check for indicators of the stoves usage (e.g fresh ash, burned wood, presence of charcoal, etc.) </p>
<p>17. In the past two weeks, how many times have you used the traditional cooking stove?</p>	<p><input type="checkbox"/> Never <input type="checkbox"/> once per day <input type="checkbox"/> twice per day <input type="checkbox"/> three times per day <input type="checkbox"/> once every two days <input type="checkbox"/> once per week <input type="checkbox"/> twice per week</p>
<p>18. In the past two weeks, how many times have you used the energy efficient firewood stove?</p>	<p><input type="checkbox"/> Never <input type="checkbox"/> once per day <input type="checkbox"/> twice per day <input type="checkbox"/> three times per day <input type="checkbox"/> once every two days <input type="checkbox"/> once per week <input type="checkbox"/> twice per week</p>
<p>19. How would you rank the cook stoves</p>	<p><input type="checkbox"/> 3-stone open fire</p>

<p>currently being used by the household starting with the most used to the least used</p>	<p><input type="checkbox"/> Fixed stove <input type="checkbox"/> Portable stove <input type="checkbox"/> Branded Stove <input type="checkbox"/> Gasifier Stove <input type="checkbox"/> Charcoal Stove <input type="checkbox"/> Liquefied Petroleum Gas stove <input type="checkbox"/> Biogas stove <input type="checkbox"/> Electric cooker <input type="checkbox"/> Kerosene stove</p>
<p>20. What is your main fuel used for cooking?</p>	<p><input type="checkbox"/> Firewood <input type="checkbox"/> Charcoal <input type="checkbox"/> Agricultural residues <input type="checkbox"/> Liquefied Petroleum Gas <input type="checkbox"/> Kerosene <input type="checkbox"/> Electricity <input type="checkbox"/> Biogas <input type="checkbox"/> Other, specify.....</p>
<p>21. Besides the main fuel, what are the OTHER fuels used for cooking in your household?</p>	<p><input type="checkbox"/> Firewood <input type="checkbox"/> Charcoal <input type="checkbox"/> Agricultural residues <input type="checkbox"/> Liquefied Petroleum Gas <input type="checkbox"/> Kerosene <input type="checkbox"/> Electricity <input type="checkbox"/> Biogas <input type="checkbox"/> Other, specify.....</p>
<p>C. Information on the household's cooking pattern</p>	
<p>22. How many times do you cook per day on average? (normal cooking pattern in a year)</p>	<p><input type="checkbox"/> once every day <input type="checkbox"/> twice every day <input type="checkbox"/> three times every day <input type="checkbox"/> every two days <input type="checkbox"/> once per week <input type="checkbox"/> twice per week <input type="checkbox"/> other (specify).....</p>
<p>23. If not cooking everyday, what are the reasons</p>	<p>..... </p>
<p>24. How many times do you averagely cook per day on the energy efficient firewood stove? (normal cooking pattern in a year)</p>	<p><input type="checkbox"/> once per day <input type="checkbox"/> twice per day <input type="checkbox"/> three times per day <input type="checkbox"/> every two days <input type="checkbox"/> twice per week <input type="checkbox"/> once per week <input type="checkbox"/> other, specify.....</p>

<p>25. If not cooking everyday on the energy efficient firewood stove, what are the reasons</p>	<p>..... </p>
<p>26. On average how long does it take you to prepare a meal for your household? (normal cooking pattern in a year)</p>	<p><input type="checkbox"/> Breakfast..... <input type="checkbox"/> Lunch..... <input type="checkbox"/> Supper..... <input type="checkbox"/> Other (specify).....</p>
<p>27. Does the family cook more or less food with the energy efficient firewood stove compared to the traditional stove in a day?</p>	<p><input type="checkbox"/> More <input type="checkbox"/> Less <input type="checkbox"/> No difference</p>
<p>28. If more food, please indicate how many more plates in a day and the reason.</p>	<p><input type="checkbox"/> less than 2 plates <input type="checkbox"/> 2-5 plates <input type="checkbox"/> 5-10 plates <input type="checkbox"/> above 10 plates Reasons, why cook more </p>
<p>29. If less food, please indicate how many less plates in a day and the reason.</p>	<p><input type="checkbox"/> <2 plates <input type="checkbox"/> 2-5 plates <input type="checkbox"/> 5-10 plates <input type="checkbox"/> above 10 plates Reasons, why cook less </p>
<p>30. Which 3 TYPES of food must you still often cook on your traditional stove throughout the year even after the purchase/installation of the energy efficient stove?</p>	<p><input type="checkbox"/> None <input type="checkbox"/> Please list food types (if any): 1. 2. 3. Specify, why this food is cooked on traditional stove: <input type="checkbox"/> long to cook <input type="checkbox"/> the cooking surface can be enlarged</p>

	<input type="checkbox"/> other (specify)..... ...
31. Under what circumstances must you still cook on your traditional stove	<input type="checkbox"/> None <input type="checkbox"/> Please specify (if any):
D. Information on firewood consumption	
32. Do you usually collect or buy your fuel?	<input type="checkbox"/> Collect <input type="checkbox"/> Buy
33. If you collect firewood, how long in hours is the distance to the firewood collection area?	<input type="checkbox"/> < 1hr <input type="checkbox"/> 1hr <input type="checkbox"/> >1hr<2 <input type="checkbox"/> 2hrs <input type="checkbox"/> > 2hrs
34. If you collect firewood, where do you get it from?	<input type="checkbox"/> My/our farmland <input type="checkbox"/> Bushes around <input type="checkbox"/> Indigenous forests <input type="checkbox"/> Planted forests (private or public) <input type="checkbox"/> Gazetted forests <input type="checkbox"/> Other (specify).....
35. If you buy, how much do you averagely spend on firewood used for cooking every week?	<input type="checkbox"/> <50 KES <input type="checkbox"/> 50-100 KES <input type="checkbox"/> 100-200 KES <input type="checkbox"/> 200-500 KES <input type="checkbox"/> >500 KES
36. Who is responsible for the firewood collection/purchase?	<input type="checkbox"/> mother <input type="checkbox"/> children <input type="checkbox"/> father <input type="checkbox"/> house-help <input type="checkbox"/> mother/children
37. Do you use more or less fuel during the rainy season compared to the dry season?	<input type="checkbox"/> more in rainy season compared to dry season <input type="checkbox"/> less in rainy season compared to dry season <input type="checkbox"/> no difference ***** Please indicate how many sticks more or less used per week: <input type="checkbox"/> <5 sticks <input type="checkbox"/> 5-10 sticks <input type="checkbox"/> 10-15 sticks <input type="checkbox"/> 15-20 sticks <input type="checkbox"/> 20-30 sticks <input type="checkbox"/> above 30 sticks

<p>38. Do you use more or less fuel during the weekend compared to weekdays?</p>	<p><input type="checkbox"/> more on weekends compared to weekdays <input type="checkbox"/> less on weekends compared to weekdays <input type="checkbox"/> no difference ***** Please indicate how many sticks more or less used per weekend: <input type="checkbox"/> <5 sticks <input type="checkbox"/> 5-10 sticks <input type="checkbox"/> 10-15 sticks <input type="checkbox"/> 15-20 sticks <input type="checkbox"/> 20-30 sticks <input type="checkbox"/> above 30 sticks</p>
<p>39. How do you compare your fuel consumption before and after the energy efficient stove purchase/installation.</p>	<p><input type="checkbox"/> Consume more now <input type="checkbox"/> consume less now ***** Please rate the change <input type="checkbox"/> By less than half <input type="checkbox"/> By half <input type="checkbox"/> By more than half</p>
<p>40. How do you compare the energy efficient stove and traditional stove in terms of firewood consumption. Which one consumes less firewood?</p>	<p><input type="checkbox"/> Traditional stove <input type="checkbox"/> Energy efficient stove</p>
<p>41. How do you compare the energy efficient stove and traditional stove in terms of smoke emission. Which one produces less smoke?</p>	<p><input type="checkbox"/> Traditional stove <input type="checkbox"/> Energy efficient stove</p>
<p>E. Information on customer service and satisfaction</p>	
<p>42. Are you satisfied with the energy efficient firewood stove you purchased/installed in terms of ...?</p>	<p>The design : <input type="checkbox"/> Yes <input type="checkbox"/> No, reason why not</p> <p>The cooking efficiency: <input type="checkbox"/> Yes <input type="checkbox"/> No, reason why not</p> <p>Cost of purchase: <input type="checkbox"/> Yes <input type="checkbox"/> No, reason why not</p>

	<p>Overall quality: <input type="checkbox"/> Yes <input type="checkbox"/> No, reason why not</p> <p>Fuel availability: <input type="checkbox"/> Yes <input type="checkbox"/> No, reason why not</p> <p>Usage experience: <input type="checkbox"/> Yes <input type="checkbox"/> No, reason why not</p> <p>After purchase service (warranty, repair): <input type="checkbox"/> Yes <input type="checkbox"/> No, reason why not</p> <p>The provided user information: <input type="checkbox"/> Yes <input type="checkbox"/> No, reason why not</p>
<p>43. Did you get sensitized or given user instruction when you purchased/installed the stove?</p>	<p><input type="checkbox"/> Yes <input type="checkbox"/> No</p>
<p>44. If yes in 43 above, how would you rate the information/user instruction given?</p>	<p><input type="checkbox"/> Highly helpful <input type="checkbox"/> Helpful <input type="checkbox"/> Not helpful <input type="checkbox"/> Not given</p>
<p>45. What general comments/concerns could you wish to share!</p>	<p><input type="checkbox"/> Encourage use of stove <input type="checkbox"/> Good Work by the promoters <input type="checkbox"/> Proper training of artisans <input type="checkbox"/> Any others, specify.....</p>
<p>46. Stove Location</p>	<p>Pick the GPS location of the stove</p> <p>Latitude:</p> <p>Longitude:</p>

Appendix III: Kitchen Performance Test (KPT) Questionnaire

A. Information on Household/stove user	
1. Are you the primary cook or stove user?	<input type="checkbox"/> Yes <input type="checkbox"/> No
2. Gender	<input type="checkbox"/> Male <input type="checkbox"/> Female
3. Age	<input type="checkbox"/> Below 18 yrs <input type="checkbox"/> 18-27 yrs <input type="checkbox"/> 28-37 yrs <input type="checkbox"/> 38-47 yrs <input type="checkbox"/> 48-57 yrs <input type="checkbox"/> 58-67 yrs <input type="checkbox"/> Above 67 yrs
4. Education Level	<input type="checkbox"/> None <input type="checkbox"/> Primary <input type="checkbox"/> Secondary <input type="checkbox"/> College <input type="checkbox"/> University
5. Number of persons permanently living in the household	Adults (above 18 yrs)..... Children (below 18 years)..... Total:.....
6. Stove Location	Pick the GPS location of the stove Latitude: Longitude:
B. Information on stove usage during 7 days KPT period	
7. Number of family members cooked for during the past week?	Adults (above 18 yrs)..... Children (below 18 years)..... Total:
8. The 3 most COMMON types of food cooked over the past week?	1..... 2..... 3.....
9. Besides the supplied pile of firewood, did you use any OTHER fuels for cooking in your household in the past week?	<input type="checkbox"/> Yes <input type="checkbox"/> No
10. If Yes in 3 above, please list and quantify the other fuels used	<input type="checkbox"/> Secondary fuel:..... <input type="checkbox"/> Tertiary fuel:.....

	<p>*****</p> <p>Please indicate the quantity of the other fuels used:</p> <p><input type="checkbox"/> Secondary fuel:/week</p> <p><input type="checkbox"/> Tertiary fuel:...../week</p>
<p>11. How many times did you cook per day on the energy efficient stove in the past week?</p>	<p><input type="checkbox"/> once per day</p> <p><input type="checkbox"/> twice per day</p> <p><input type="checkbox"/> three times per day</p> <p><input type="checkbox"/> every two days</p> <p><input type="checkbox"/> twice per week</p> <p><input type="checkbox"/> once per week</p> <p><input type="checkbox"/> other (specify).....</p> <p>*****</p> <p><input type="checkbox"/> reasons for not cooking every day :</p>
<p>12. Has this week been in any way different from normal weeks?</p>	<p><input type="checkbox"/> Yes</p> <p><input type="checkbox"/> No</p> <p>*****</p> <p>*****</p> <p><input type="checkbox"/> If yes, please explain why</p>

Fuel Consumption

Day	Mass of firewood measured (kg)	Mass of firewood added (kg)	Total Mass of firewood consumed up until this day
1		-	-
3			
5			
7			

Appendix IV: Key Informant Interview (KII) Schedule

Thank you for the opportunity to have this interview with you. I am Victor Omondi John, a Master's student at MMUST, working on a thesis whose purpose is to evaluate the contributions of sustained usage of energy efficient firewood cook stoves to climate change mitigation in Siaya County. I will try keep the interview short and hope that it will not last more than 30 minutes. Any information you provide will be kept anonymous and confidential. Just in case you have anything I may need to clarify further; I would wish to do it before we start. If not, we can now go ahead.

1. Have you ever been in any way engaged in any energy efficient firewood cook stove promotion program? If yes, for how long? Are there any lessons or experiences you can share?
2. If you may be aware, what are some of the types of energy efficient firewood cook stove used in Siaya County?
3. In your opinion, what are some of the socio-economic factors that have influenced stove adoption and usage in Siaya County?
4. Where do you think households in Siaya collect firewood from? In your opinion has the way firewood is being collected/extracted had any impacts on the environment?
5. Comment briefly on the level of awareness of Siaya households on the role of energy efficient cook stoves to climate change mitigation?
6. What do you think can be done to improve energy efficient firewood stoves adoption and sustained usage in Siaya County?
7. What general comments/concerns could you wish to share?

Appendix V: NACOSTI Permit

REPUBLIC OF KENYA
Ministry of Science, Technology and Innovation
National Commission for Science, Technology and Innovation

Ref No: **681557** Date of Issue: **05/April/2024**

RESEARCH LICENSE



This is to Certify that Mr. Victor Omondi John of Mazinde Maitiro University of Science and Technology, has been licensed to conduct research as per the provision of the Science, Technology and Innovation Act, 2013 (Rev.2014) in Siaya County, Kenya, on the topic: Effect of sustained usage of energy efficient firewood cook stove on climate change mitigation in Siaya County, Kenya, for the period ending : 05/April/2025.

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